Essays on Macroeconomic Policy

Inauguraldissertation
zur Erlangung des akademischen Grades
eines Doktors der Wirtschaftswissenschaften
der Universität Mannheim

im Frühjahrs-/Sommersemester 2022 vorgelegt von

Alexander Matusche

Abteilungssprecher: Prof. Volker Nocke, Ph.D.
Vorsitzender der Disputation: Prof. Dr. Carsten Trenkler
Referent: Prof. Tom Krebs, Ph.D.
Korreferent: Prof. Antoine Camous, Ph.D.

Tag der Disputation: 23. Juni 2022

Eidesstattliche Erklärung

Hiermit erkläre ich, dass ich die Arbeit selbstständig angefertigt und die benutzten Hilfsmittel vollständig und deutlich angegeben habe.

Mannheim, am 11. Mai 2022

Alexander Matusche

Curriculum Vitae

2016–2022	University of Mannheim (Germany) *Ph.D. in Economics*
2020	Yale University, New Haven (Connecticut, USA) *Visiting Ph.D. Student*
2013–2016	University of Cologne (Germany) *Master of Science in Economics*
2012	University of British Columbia, Vancouver (Canada) *Visiting Student*
2010–2013	University of Cologne (Germany) *Bachelor of Science in Economics*

Acknowledgments

I am very grateful to my advisor, Tom Krebs, for his continuous guidance and support. Many conversations over the years have not only greatly influenced this dissertation and challenged my thoughts many times, but have also shaped my thinking as an economist more generally. I would like to thank to Antoine Camous and Andreas Gulyas for many helpful comments on my work and for raising lots of important questions. Their feedback has greatly improved this dissertation.

My work has also benefitted from insightful conversations with and feedback from Klaus Adam, Antonio Ciccone, Lukas Hack, Anne Hannusch, Zhen Huo, Matthias Meier, Oliver Pfäuti, Daniel Runge, Konrad Stahl, Michael Sockin, Jan Sun, and Michèle Tertilt. I am especially grateful to Matthias Meier for his encouragement with my very first research project, which has evolved into the second chapter of this dissertation.

I greatly appreciated the support from Corinna Jann–Grahovac at the University of Mannheim Department of Economics and Ulrich Kehl, Caroline Mohr, and Marion Lehnert at the Center for Doctoral Studies in Economics.

The fellow students of my PhD class, Johannes Gönsch, Maximilian Jager, Xi Lin, Michaela Paffenholz, Timo Reinelt, Karl Schulz, Sebastian Seitz, Mark Spills, Johannes Wacks, and Frederick Zadow, have made my time in Mannheim much more fun and enjoyable and have become good friends. It was comforting to know that I could turn to them at any point. Johannes Wacks is the co-author of Chapters 2 and 3, long-time office mate, and close friend. I am thankful for his support in every one of these roles. Many conversations over the years were not only great fun but have also taught me a lot about economics. Numerous times Johannes's perceptive comments and questions made me reassess the soundness of an argument and challenged me to make a vague intuition more precise.

I am grateful for interesting conversations and companionship with Andrey Alexandrov and Tsung-Hsien Li during our time in New Haven and beyond, and I thank Paul Gorny for his support and many helpful conversations at very different stages of my studies, from undergraduate to PhD.

I want to thank my girlfriend, Prakriti Gill. She made many things much easier and her constant support helped me overcome many challenges. Finally, I thank my parents and my sister. I am extremely grateful for all they have done for me.

Contents

Preface

This dissertation consists of three self-contained chapters. They share the focus on the short-run effects of macroeconomic policies. In Chapter 1, I study a particular fiscal policy: public infrastructure investment; Chapters 2 and 3 deal with the role of wealth inequality for the transmission of monetary policy. In the following, I provide a summary of each chapter.

Chapter 1: The Short-Run Employment Effects of Public Infrastructure Investment
In the first chapter, I use a model with search and matching in the labor market to study the stimulus effects of a permanent expansion in public investment that raises productivity over time. In the frictional labor market, firms hire workers for multiple periods. When the government announces an expansion in public investment, firms anticipate positive effects on labor productivity, expect high labor demand in the future, and rush to hire workers while they are still easy to find. Through this *anticipation effect on labor demand*, the policy change causes an immediate increase in employment even if implementation lags delay the actual expansion in public investment after it has been announced.

First, I describe this effect theoretically. To this end, I define the *employment multiplier of public investment* as the change in employment in response to a permanent expansion of public investment in the future. I characterize the employment multiplier analytically and study its determinants. It is increasing in the output elasticity of public investment and decreasing in the implementation lag. I show that the employment multiplier is larger when public investment increases during a recession with high unemployment compared to a boom with low unemployment.

Second, I use the model to quantify the employment effect of a permanent expansion in public investment. I calibrate the model to the US economy and show that it matches standard business cycle moments. The calibrated model yields an increase in employment by 0.4 percentage points one year after a permanent expansion of public investment by 1% of GDP. The anticipation effect accounts for up to 65% of the additional employment, and is more important than the realized increase in productivity during the first year. When the economy is in a recession with high unemployment and weak labor demand, the employment gain is 40% larger than in a boom. Implementation delays lower the employment effect of public investment, but it is also substantial with such delays. Even when one year passes between the announcement of the expansion in public investment and the actual implementation, employment increases by about 0.25 percentage points within the first year after the announcement. If the expansion in public investment is financed with distortionary taxes, the increase in employment is smaller, but it remains positive and sizeable.

Chapter 2: Does Wealth Inequality Affect the Transmission of Monetary Policy?
This chapter is joint work with Johannes Wacks.

Wealth inequality in the US and other advanced economies has increased since the mid 1980s. In this chapter, we investigate the consequences of this increase for the transmission of monetary policy to the real economy. We show empirically, that greater wealth inequality is associated with stronger real effects of monetary policy.

We take three different approaches. First, we use aggregate time series data to estimate state-dependent local projections for the US and the UK, using wealth inequality as the state variable. We find that, in both economies, policy rate changes had larger effects on output and unemployment when wealth inequality was higher. Second, we use estimates on wealth held by the richest households from the Internal Revenue Service to construct a new measure of wealth inequality at the US state level. We estimate the responses of output and unemployment to changes in the federal funds rate, and find that they are larger in states with greater wealth inequality. Third, we estimate wealth inequality in every Euro Area country from microdata of the ECB's Household Finance and Consumption Survey. Using the estimates of wealth inequality, we provide evidence that Euro Area countries with a more unequal wealth distribution exhibit larger responses of output and unemployment to common ECB monetary policy.

Taken together, the three different approaches all lead to the same conclusion, namely that greater wealth inequality is associated with stronger effects of monetary policy on economic activity.

Chapter 3: Monetary Policy and Wealth Inequality—The Role of Entrepreneurs
This chapter is joint work with Johannes Wacks.

We document a shift of household wealth from workers to entrepreneurs since the 1980s and ask how such a shift matters for the transmission of monetary policy to the real economy, in particular aggregate investment. To answer this question, we develop a Heterogeneous Agent New Keynesian (HANK) model with entrepreneurs who invest in their private businesses. The business produces with decreasing returns to scale and features idiosyncratic risk.

Entrepreneurs can only use their own funds to finance investment in their business. They cannot directly insure against the risk associated with the firm. Because of the decreasing returns to scale and the uninsurable risk, entrepreneurs' net worth determines the size of their firm. Richer entrepreneurs are well insured and can bear the firm risk more easily than poorer entrepreneurs. As a result, richer entrepreneurs own larger firms and earn smaller returns. When monetary policy lowers the interest rate, the excess returns of private firms over the risk-free interest rate increase and entrepreneurs expand investment in their firm. However, the strength of this portfolio reallocation depends on entrepreneurs' net worth. Rich entrepreneurs earn lower excess returns which rise relatively more than the high excess returns of poor entrepreneurs with small businesses. As a result, rich entrepreneurs expand firm investment more strongly than poorer entrepreneurs.

We calibrate the model to the US economy, targeting the size of the entrepreneurial sector and the shares of liquid and illiquid assets held by workers and entrepreneurs. The model matches the distribution of private business returns over owners' net worth observed in the Survey of Consumer Finances, although we do not target it in the calibration. This is important because, as explained above, the excess return over the risk-free rate determines the strength of portfolio reallocation towards the private business in response to a policy rate cut.

The model yields two main results. First, entrepreneurs are quantitatively important for the transmission of monetary policy, although they only account for 7.5% of all households. If entrepreneurs do not respond to changes in the interest rate, the induced output response is about 50% smaller. Second, when entrepreneurs hold relatively more wealth, the real effects of monetary policy are stronger. A shift of wealth from workers to entrepreneurs, which increases the share of the richest 10% of households by 1 percentage point, raises the output response to an interest rate change by 3% to 20%, depending on how the wealth is distributed among entrepreneurs.

Chapter 1

The Short-run Employment Effects of Public Infrastructure Investment

1 Introduction

On November 5, 2021, the US Congress passed the "Infrastructure Investment and Jobs Act", which appropriates $550 billion for additional federal infrastructure investment to be spent over the next five years. This would raise federal non-defense infrastructure investment from 0.7% of GDP in 2019 to about 1.3%, a level last seen in the 1970s. Also in Europe, there are plans to expand infrastructure investment. For example, the EU Recovery Fund allocates at least €383 billion to public investment supporting green and digital transformation.[1] These expansions of public investment were put forward during a recession with high unemployment and a potential need for fiscal stimulus. Whether a public investment program can provide such short-term stimulus is a debated question. Summers (2009) has argued in favor of expanding public investment during a recession. Ramey (2020) sees little expansionary effects, if any at all, of expanding public investment during a recession and argues that government consumption likely has larger short-run effects than public investment.

This paper contributes to this debate. I ask whether a lasting expansion of public infrastructure investment can raise employment in the short run. Can policymakers initiate such a change during a recession to stimulate the economy?

A vast literature has found large positive effects of public investment on productivity and output *in the long run*.[2] In this paper, I take these positive long-run effects as given and show that they can lead to a substantial increase in employment already in the short run. Quantitatively, a permanent expansion in public investment by 1% of GDP raises employment by 0.4 percentage points within one year.

---

[1] The "Recovery and Resilience Facility" contains a total of 672.5 billion Euros of which 57% have to be allocated by the member states to investments and reforms supporting green and digital transformation.

[2] See for example Aschauer (1989), Bom and Ligthart (2014), Bouakez et al. (2017), Cubas (2020), Munnell (1990), and Pereira and Frutos (1999). I discuss this literature in detail in Section 4.

The reason for the positive employment effects in the short run is an *anticipation effect on labor demand*. When public investment increases, firms anticipate higher private factor productivity and tighter labor markets in the future. They expand hiring already in the present when it is still relatively cheap since labor market tightness is low and workers can be found quickly. In a recession, when unemployment is temporarily high, additional labor demand impairs the ability of other firms to find workers less strongly than during a boom. Thus, the employment effect is particularly large. To the best of my knowledge, this paper is the first to state and quantify the anticipation effect of public investment on labor demand and its business cycle dependence.[3]

Labor market frictions are essential for the increase in labor demand in response to higher future productivity. I model them following Mortensen and Pissarides (1994) and Pissarides (1985). Firms enter the labor market by posting vacancies. After a firm has filled a vacancy and hired a worker, it produces output until the worker is separated from the firm. Importantly, there is a positive probability that a firm-worker match lasts more than one period. This renders firms' hiring decision forward-looking, allows firms to engage in labor hoarding, and gives rise to the anticipation effect on labor demand. In contrast, when firms hire labor period by period, as in much of the literature on public investment (e.g. Baxter and King 1993; Boehm 2020), there is no anticipation effect on labor demand.

Public investment may also stimulate labor demand directly as the public sector and its contractors hire workers to implement infrastructure projects. For example, Michaillat (2014) finds large aggregate employment effects of public sector hiring especially during recessions. Rendahl (2016) studies the effects of public spending on employment through aggregate demand in a matching model and finds large effects during a recession. In this paper, I abstract from these demand channels and focus on the effect on employment that is due to rising long-run productivity and, therefore, specific to public investment. In this view, the employment effects I find here can be interpreted as the effects of government investment in excess of those of consumptive government spending.

In the first part of this paper, I analyze the employment effects of public investment theoretically. I assume that labor supply is constant to focus on the anticipation effect on labor demand. I define the *employment multiplier of public investment*: the change in employment following the announcement of a permanent expansion in public investment by one dollar starting at some point in the future. The employment multiplier is strictly positive in the short run even if it is zero in the long run. Thus, the positive employment multiplier is a transitional phenomenon: A higher level of public investment does not imply higher employment in the steady state. Instead, it is the increase in public investment and not the higher level that raises employment in the short run.

For the case where the economy is in the steady state initially, I derive an analytic

---

[3] In a comment to Monacelli et al. (2010), Merz (2010) mentions that positive effects on labor productivity of government spending may lead to larger multipliers in a search and matching model.

expression for the employment multiplier. The formula highlights the role of future productivity for the evolution of employment and makes transparent how parameter assumptions and implementation delays shape the multiplier. It is larger if an increase in public investment has greater effects on productivity in the long run. This also means that public investment has larger short-run effects than government consumption which does not have any effects on productivity.

Wage stickiness also amplifies the employment effect; when wages rise more slowly following the rise in future productivity, labor hoarding is cheaper and firms expand vacancy creation in the short run more strongly.

Implementation delays reduce the employment multiplier. When they are longer, productivity only increases in the more distant future. Therefore, a worker hired today is less likely to be employed at the firm when the productivity effect of investment materializes and the effect on the present value of match output is smaller. Hence, firms expand vacancy creation less strongly in the short run.

I investigate how the employment multiplier differs between recessions and normal times. The employment multiplier is larger when unemployment is high. In this case, an additional vacancy only leads to a small increase in labor market tightness. Therefore, it does not reduce the rate at which other firms can fill their vacancies much; the congestion externality is small.

I also characterize the welfare consequences of public investment. In general, the search and matching equilibrium is not constrained-efficient, because firms neither internalize the positive effect of vacancy creation on the job-finding probability of workers nor the negative effect on the vacancy-filling probability of other firms. Hence, there may be too much or too little vacancy creation in equilibrium. When there is inefficiently little vacancy creation because the equilibrium wage exceeds the Hosios wage, then the anticipation effect on labor demand brings vacancy creation closer to its efficient level.

These theoretical results rely on the assumption of a fixed labor supply. This assumption allows me to focus on the new mechanism in my model, the anticipation effect of public investment on *labor demand*. However, public investment could also affect *labor supply* in the short run. For example, Leeper et al. (2010) find that an increase in future productivity lowers labor supply through a wealth effect such that public investment has smaller output effects than unproductive spending. In my model, when labor supply is endogenous because unemployed workers choose search effort, the sign of the employment multiplier of public investment is theoretically ambiguous. In response to an expansion in public investment, workers might increase or decrease search effort in the short run. Higher future wages induce workers to search more intensely, whereas better job-finding prospects in the long run lead to lower search effort in the present. How employment responds to an expansion in public investment is thus a quantitative question to which I turn in the second part of this paper.

I calibrate the model to match transition rates between unemployment and employment which I estimate from CPS microdata. The model replicates standard moments of the US business cycle such as the volatility and persistence of unemployment, output, and investment. In general, it is difficult for the standard search and matching model to generate enough volatility of unemployment over the business cycle (Shimer 2005). My model matches the observed volatility for two reasons. First, the profit share is relatively small because capital is a second production factor and its costs diminish profits. Second, wages exhibit substantial inertia.

I consider a permanent expansion of public infrastructure investment by 1% of GDP. First, I assume that the public investment program is implemented as soon as it is announced and that it is financed with lump-sum taxes. The permanent expansion of public investment leads to a long-run increase in productivity by 3%. It takes about 25 years until productivity reaches its new long-run level. After one year, the expansion of public investment has increased productivity by only 0.35%, but unemployment is already 0.4 percentage points lower than before. I quantify the contribution of the anticipation effect and find that it accounts for up to 65% of the employment gain after one year.

Second, I consider implementation lags. They reduce the employment response upon announcement of the expansion in public investment, but the response remains large. For example, when one year passes between the announcement and the implementation of the investment program, unemployment still declines by 0.25 percentage points within the first year after announcement of the program. Third, when the government levies distortionary labor taxes to finance the additional public investment, the employment effect is smaller but still positive. The reduction in unemployment one year after the beginning of the investment program is still close to 0.25 percentage points. Finally, the employment effect is more than 40% larger in a recession than in a boom.

Wage inertia is quantitatively important for the large employment gains in the short run. Under my calibration, wages increase almost in proportion to productivity. If wage inertia is smaller, expectations about higher future productivity lead to a stronger wage increase in the short run as workers demand higher wages. This makes labor hoarding more costly for firms and the employment effect is smaller.

My results imply that recessions are good times to announce a change in fiscal policy towards more public infrastructure investment. The policy change can stimulate employment in the short run even if there are substantial implementation delays, and the employment reduction and the associated output gains are particularly large in a recession.

Related Literature A large literature in macroeconomics studies fiscal multipliers. Two strands of this literature are related particularly closely to the present paper. The first is the literature on the short-run effects of public investment (Baxter and King 1993; Boehm 2020; Leeper et al. 2010; Ramey 2020). These studies find smaller short-run effects of public investment than of government consumption because the long-run productivity gains associated with public investment push down labor supply in the short-run through a positive wealth effect. Except for Ramey (2020), these papers consider frictionless labor markets. Firms' labor demand decision is static, independent of future productivity and only the labor supply decision of workers is directly affected by changes in expected future productivity due to public investment. The model in Ramey (2020) features labor market frictions in the form of sticky wages, but labor demand is still a static decision. Instead, I study a model with search frictions in the labor market in which labor demand depends on future productivity. I find that the short-run employment effects of public investment are significantly larger than those of unproductive government spending.

I share the emphasis on frictional labor markets with a second strand of literature. Mitman and Rabinovich (2015) focus on unemployment benefit extensions, Monacelli et al. (2010) and Rendahl (2016) investigates government consumption, and Michaillat and Saez (2018) and Michaillat (2014) study public sector employment. I add an analysis of a different type of government spending, public investment, which has not been studied in the context of search and matching in the labor market.

This paper is also related to the literature on news-driven business cycles following Beaudry and Portier (2006) who find that anticipated future TFP growth is an important source of business cycle fluctuations (Beaudry and Portier 2007; Schmitt-Grohé and Uribe 2012). In my model, public investment alters expectations about private future productivity and as such constitutes a news shock causing an expectations-driven boom.[4] Thus, it is closely related to Den Haan and Kaltenbrunner (2009) who also study a model with matching frictions and find that news about higher future productivity can generate a boom in investment, hours worked, consumption and output before productivity actually increases. My paper differs in the following ways. First, I analyze the employment effect theoretically. Second, I consider anticipated changes in productivity caused by public investment. Since public investment is costly, the government has to raise revenues to finance it and I study the effects of public investment under different assumptions about its financing, lump-sum taxes and distortionary labor taxes. The short-run employment effects of public investment are positive even if financed with distortionary taxes (see Section 5.4). Third, I show that the employment effects can be substantially larger in recessions.

Outline The remainder of the paper is structured as follows. In Section 2, I present the model. In Section 3, I define the employment multiplier of public investment and analyze it theoretically. I calibrate the model in Section 4 and quantify the employment and output effects of public investment in Section 5. Section 6 concludes.

---

[4] I show in Appendix C.3 that the employment effect of public investment when financed with lump-sum taxes, is proportional to the employment effect of a permanent increase in productivity.

2 Model

The model features random search and matching in the labor market following Diamond, Mortensen and Pissarides (DMP model). Firms need two types of capital to produce: private and public capital. Firms rent private capital from households whereas the government provides the public capital stock, which is used in production by all firms simultaneously—it is a public good. Time $t = 0, \ldots, \infty$ is discrete and runs forever.

2.1 Firms, labor market, and production

There is a large number of firms. Each firm can hire a worker to produce output, y_t, using the worker's labor, private capital, k_t, and public capital, K_t^G, according to the production function

$$y_t = A_t \left(K_t^G\right)^{\vartheta} k_t^{\alpha}. \tag{1.1}$$

Here, A_t is a measure of exogenous productivity and ϑ is the output elasticity of public capital. The public capital stock K_t^G is a public good. All firms can use it simultaneously and there is no congestion externality. This is why the aggregate stock of public capital enters the production function of every individual firm. Since firms cannot be excluded from using it, the government provides the public capital stock. The production function (1.1) follows Baxter and King (1993) and is the standard way to incorporate public capital in a macroeconomic model. Equivalently, we can write the production function as $y_t = z_t k_t^{\alpha}$, where

$$z_t = A_t \left(K_t^G\right)^{\vartheta} \tag{1.2}$$

is total productivity of private factors (TFP). It depends positively on the public capital stock but is taken as given by private firms.

To hire a worker, a firm has to post a vacancy at per-period cost κ_t. I think of these costs as the foregone production of those workers involved in the hiring process such that vacancy posting costs are proportional to labor productivity y_t,

$$\kappa_t = \bar{\kappa} \cdot y_t,$$

and $\bar{\kappa}$ is the amount of labor required to open a vacancy measured in full-time equivalents. With posting costs proportional to labor productivity, unemployment is constant in the long run even if productivity grows over time. In this sense, posting costs that are proportional to labor productivity ensure that the model is consistent with balanced growth. In contrast, if posting costs were constant, productivity growth would lead to a sustained decline in unemployment as the costs of posting a vacancy would fall relative to output of a filled vacancy.

Let v denote the measure of open vacancies and let L^u denote aggregate search effort, which is individual search effort of unemployed workers aggregated over all unemployed workers. We can think of individual search effort as the number of applications sent out by a single unemployed worker. Then, aggregate search effort would be the number of all applications sent in the economy. In equilibrium, all unemployed households will search with the same intensity, such that aggregate search effort is simply individual search effort, ℓ, times the measure of unemployed workers U, $L^u = U\ell$. The number of vacancies v and aggregate search effort L^u determine the number of firm-worker matches formed in a given period according to the Cobb-Douglas matching function

$$M(L^u, v) = \zeta \left(L^u\right)^{\eta} (v)^{1-\eta}, \text{ with } \eta \in (0,1). \tag{1.3}$$

More matches are formed if firms create more vacancies, there are more unemployed workers looking for a job, or if unemployed workers search with greater intensity (send more applications in the previous example).

With $M(L_t^u, v_t)$ matches created in period t, there are $\frac{M(L_t^u, v_t)}{v_t}$ matches for every vacancy. Since matching is random, every firm with an open vacancy finds a worker with the same probability

$$q_t^v(\theta_t) = \frac{M(L_t^u, v_t)}{v_t} = \zeta \theta_t^{-\eta},$$

where $\theta_t \equiv \frac{v_t}{L_t^u}$ denotes labor market tightness.

When a firm has filled its vacancy, it rents private capital from households at rate r_t^k, produces output according to (1.1), and pays the wage w_t to its worker.

The match between worker and firm is dissolved with probability $\rho < 1$ and continues to exist in the next period with the complementary probability $1 - \rho$. The value of a firm with a filled vacancy is

$$J_t^F = \max_k \; z_t k^{\alpha} - w_t - r_t^k k + \beta \Big\{ \rho V_{t+1} + (1-\rho) J_{t+1}^F \Big\}, \tag{1.4}$$

where V_{t+1} is the value of an open vacancy in the next period defined below and β is the firm's discount factor.[5]

The first-order condition for the optimal choice of capital in (1.4) is that the rental rate for capital equals the marginal product of capital,

$$r_t^k = \alpha z_t k_t^{\alpha - 1}. \tag{1.5}$$

Using the first-order condition, the value of a filled vacancy can be written as

$$J_t^F = (1-\alpha) z_t k_t^{\alpha} - w_t + \beta \Big\{ \rho V_{t+1} + (1-\rho) J_{t+1}^F \Big\}.$$

---

[5] The firm's discount factor equals the discount factor of its owner, which is constant because firm owners have linear utility.

The value of an open vacancy is

$$V_t = -\kappa_t + \beta \left\{ q_t^v J_{t+1}^F + (1 - q_t^v) V_{t+1} \right\}. \tag{1.6}$$

It consists of the costs of opening a vacancy and the expected return: with probability q_t^v, the firm finds a worker and receives the value of a filled vacancy, J_{t+1}^F.

Because any firm can open a vacancy, the value of opening a vacancy must be zero in equilibrium. This implies that equilibrium labor market tightness solves the job creation equation

$$\frac{\kappa_t}{q_t^v(\theta_t)} = \beta \left\{ (1-\alpha) z_{t+1} k_{t+1}^{\alpha} - w_{t+1} + (1-\rho) \frac{\kappa_{t+1}}{q_{t+1}^v(\theta_{t+1})} \right\}. \tag{1.7}$$

Since $\frac{1}{q_t^v}$ is the average time to fill a vacancy, the left-hand side of (1.7) is the expected cost to fill a vacancy. In equilibrium, it has to be equal to the value of a filled vacancy on the right-hand side. The value of a filled vacancy consists of discounted output net of wages and capital costs in the next period plus the expected future value of a match, taking into account that the match survives with probability $1 - \rho$.

Equation (1.7) highlights the forward-looking nature of firms' vacancy posting decision and already contains the main intuition for the labor demand effects of public investment. A persistent expansion of public investment leads to a gradual rise in the public capital stock which raises private productivity z in the future. This leads to an increase in future labor market tightness such that the average time to fill a vacancy in the future increases. The expected costs of filling a vacancy in the future rise. As equation (1.7) shows, firms respond to higher expected costs of filling a vacancy in the future by expanding hiring in the present, thereby raising labor market tightness. The dependence of firms' vacancy posting decision on future productivity hinges on the assumption that the separation rate is smaller than one, $\rho < 1$. Only then can firms substitute hiring intertemporarily.

The job creation equation is an affine difference equation of $x_t = \frac{\bar{\kappa}}{q_t^v(\theta_t)}$. As long as the growth rate of productivity does not exceed $\frac{1}{\beta(1-\rho)}$ in the long run, it has a unique solution for x_t, and thus for labor market tightness, which satisfies the terminal condition that labor market tightness remains bounded.

Let N_t denote the measure of producing firms which equals employment since every firm employs exactly one worker. Since every firm uses k_t units of capital, the aggregate capital stock is $K_t = k_t N_t$ and aggregate output is

$$Y_t = z_t k_t^{\alpha} N_t = z_t K_t^{\alpha} N_t^{1-\alpha} = A_t \left(K_t^G \right)^{\vartheta} K_t^{\alpha} N_t^{1-\alpha}. \tag{1.8}$$

This is the same aggregate production function as in Baxter and King (1993).

2.2 Households

The household side of the model consists of a unit mass of workers and a mass μ of homogeneous firm owners. This is a common assumption also made in Broer et al. (2019) and Ravn and Sterk (2020). Workers participate in the labor market and receive labor income when employed. Unemployed workers decide on how much effort they put into searching for employment. Firm owners do not participate in the labor market. Their income consists of firms' profits and capital returns.

Workers Workers differ regarding their labor market status s_t. They can be employed $s_t = e$ or unemployed $s_t = u$. The labor market status is risky as workers find and lose jobs stochastically. I denote the probability that a worker transitions from labor market state s to s' by $\pi^{s'|s}$.

Unemployed workers exert search effort $\ell_t \geq 0$ to find a job. The more effort an unemployed worker puts into searching, the higher the probability of finding a job. In addition to effort, the job-finding probability depends on labor market conditions summarized by labor market tightness θ_t, which is determined endogenously as described above. Since the number of matches formed per unit of aggregate search effort in period t is $\frac{M(L_t^u, v_t)}{L_t^u}$, an unemployed worker who exerts search effort ℓ_t finds a job with probability

$$\pi_t^{e|u}(\theta_t, \ell_t) = \frac{M(L_t^u, v_t)}{L_t^u}\ell_t = q_t^v(\theta_t)\theta_t\ell_t.$$

We can think of $\frac{M(L_t^u, v_t)}{L_t^u}$ as the number of matches per application sent. Since every application results in a match with the same probability (random matching), a worker who sent out ℓ_t applications, finds a job with probability $\pi_t^{e|u}(\theta_t, \ell_t) = \frac{M(L_t^u, v_t)}{L_t^u}\ell_t$.[6]

Recall, that matches between workers and firms are exogenously separated with probability ρ. Hence, the probability of losing a job is $\pi^{u|e} = \rho$. It is independent of the worker's effort. The model could easily be extended to make separations dependent on work effort.

Unemployed workers receive unemployment benefits b_t, whereas employed workers earn the wage w_t which is taxed at rate τ_t. Hence, workers face income risk. When a worker loses the job, net income falls from $(1 - \tau_t)w_t$ to b_t.

I assume that workers consume their income in every period. They do not have savings to insure against a job loss. This is a strong assumption, but a large fraction of US households are in fact hand-to-mouth, especially among the unemployed (Kaplan et al. 2014). The degree of consumption insurance during unemployment is important for the search effort decision of unemployed workers. Therefore, I calibrate the wage

---

[6] In general, the job-finding probability $\pi_t^{e|u}(\theta_t, \ell_t)$ and the vacancy filling probability $q_t^v(\theta_t)$ could exceed one. In order to interpret them as probabilities, I assume and verify that in equilibrium $M(L^U, v) < v_t$ and $M(L_t^U, v_t) < U_t$.

replacement rate of unemployment benefits to yield a realistic consumption drop upon job loss. Hand-to-mouth status of workers can also be justified as the equilibrium outcome of an extended model in which households can save in a risk-free bond but are borrowing constrained (Ravn and Sterk 2020; McKay and Reis 2021). Since workers are hand-to-mouth, consumption equals after tax income,

$$c_t(s_t) = \begin{cases} (1-\tau_t)w_t, \text{ if } s_t = e \\ b_t, \text{ if } s_t = u. \end{cases} \tag{1.9}$$

Workers value consumption and dislike effort according to the per-period utility function

$$u(c,\ell,s) = \log(c) - d(\ell,s).$$

Employed workers do not exert search effort. However, since disutility from effort depends on the employment state, the utility specification can capture a fixed disutility from working with $d(0,e) > 0$.[7]

Workers choose effort to maximize expected lifetime utility,

$$\begin{aligned} \max_{\{\ell_t(s_t),c_t(s_t)\}} \mathbb{E}_0 & \left[\sum_{t=0}^{\infty} \beta^t \left(\log(c_t(s_t)) - d(\ell_t(s_t),s_t)\right) \middle| s_0, \{\ell_t(s_t)\} \right] \\ & \text{s.t. (1.9), } \ell_t(s_t) \geq 0 \text{ and given } s_0. \end{aligned} \tag{1.10}$$

Here, the expectation is taken with respect to the labor market state s_t. The expected labor market state s_t in period t depends on the initial state s_0 and past effort choices $\{\ell_t(s_t)\}$. Expected lifetime utility of a worker in labor market state s in period t can be expressed recursively as

$$\begin{aligned} J_t(s) = & \max_{\ell,c} \log(c) - d(\ell,s) + \beta \sum_{s' \in \{e,u\}} J_{t+1}(s') \pi_t^{s'|s}(\ell,\theta_t) \\ & \text{s.t. } c = (1-\tau_t)w_t \mathbb{1}_{s=e} + b_t \mathbb{1}_{s=u}. \end{aligned} \tag{1.11}$$

The first-order condition for the optimal effort choice is

$$\frac{\partial d(\ell,u)}{\partial \ell} = \beta \left[J_{t+1}(e) - J_{t+1}(u)\right] \frac{\partial \pi_t^{e|u}(\theta_t,\ell)}{\partial \ell}. \tag{1.12}$$

The left-hand side is the utility cost of marginally increasing effort. The right-hand side is the gain in expected lifetime utility from higher effort. More search effort increases the probability of finding a job and thereby expected future income. Since all unemployed workers are identical, equilibrium search effort is the same for all unemployed workers.

---

[7] I could equivalently assume that workers exert a fixed amount of work effort whenever they are employed.

The transition probabilities between employment and unemployment imply that aggregate employment N_t evolves according to

$$N_{t+1} = (1-\rho)N_t + \pi_t^{e|u}(\theta_t, \ell_t)U_t. \tag{1.13}$$

Recall that the total mass of workers is one and every worker is either employed or unemployed. Thus, employment N_t and unemployment U_t sum to one and U_t is the unemployment rate.

Firm owners A measure μ of homogeneous firm owners own firm equity. Due to the equity ownership, each firm owner receives a dividend $\pi_t^F \equiv \frac{\Pi_t}{\mu}$, where Π_t denotes aggregate profits.

Besides equity, firm owners own the private capital stock K_t of the economy. Let k_t^F denote the amount of capital owned by an individual firm owner. It follows the law of motion

$$k_{t+1}^F = (1-\delta_k)k_t^F + i_t^F. \tag{1.14}$$

Here, δ_k is the depreciation rate of physical capital and i_t^F denotes investment in the productive capital stock. Firm owners rent out the capital stock to firms at the rental rate r_t^k. Note that the number of firm owners is constant, but the number of firms who are active and rent capital varies over time. For this reason, while aggregate capital of firm owners equals total capital used in production in equilibrium, $k_t^F \mu = k_t N_t = K_t$, capital per firm owner is not necessarily equal to capital per firm, $k_t^F \neq k_t$.

For the quantitative analysis, I assume that firm owners face quadratic adjustment costs $\phi(i_t^F, k_t^F)$ when investing in productive capital,

$$\phi(i_t^F, k_t^F) = \frac{\phi}{2}\left(\frac{i_t^F}{k_t^F} - \delta_k\right)^2 k_t^F.$$

Adjustment costs are needed for quantitatively realistic fluctuations of investment over the business cycle, but as I show in the appendix, they do not substantially affect the main results on employment. Thus, the budget constraint of an individual firm owner is

$$i_t^F + c_t^F = r_t^k k_t^F + \pi_t^F - T_t^F - \frac{\phi}{2}\left(\frac{i_t^F}{k_t^F} - \delta_k\right)^2 k_t^F, \tag{1.15}$$

where T_t^F denotes lump-sum taxes (or transfers if T_t^F is negative).[8]

---

[8] We could allow for stock trading between firm owners but since firm owners are identical, no trade would take place in equilibrium.

Firm owners are risk neutral. They maximize lifetime utility given by

$$U^F = \sum_{t=0}^{\infty} \beta^t u^F(c_t^F) = \sum_{t=0}^{\infty} \beta^t c_t^F$$

subject to the budget constraint (1.15) and the law of motion for capital (1.14). The resulting first-order condition for capital is

$$1 + \phi \left(\frac{k_{t+1}^F}{k_t^F} - 1 \right) = \beta \left(1 + r_{t+1}^k - \delta_k + \frac{\phi}{2} \left(\left(\frac{k_{t+2}^F}{k_{t+1}^F} \right)^2 - 1 \right) \right). \tag{1.16}$$

The left-hand side is the marginal cost of investing one unit of capital, which includes the marginal capital adjustment costs. The right-hand side is the marginal benefit from investing one unit of capital. It consists of the received interest payments net of depreciation and takes into account that a large capital stock in the next period affects the capital adjustment costs that have to be incurred in the next period. If the firm owner plans to grow the capital stock further in the next period, investing in the current period has the additional benefit of lower adjustment costs in the next period. The aggregate capital stock is $K_t = k_t^F \mu$ such that the first-order condition (1.16) implies that the aggregate capital stock follows the difference equation

$$1 + \phi \left(\frac{K_{t+1}}{K_t} - 1 \right) = \beta \left(1 + r_{t+1}^k - \delta_k + \frac{\phi}{2} \left(\left(\frac{K_{t+2}}{K_{t+1}} \right)^2 - 1 \right) \right). \tag{1.17}$$

Combining the first-order conditions for firms' optimal capital demand (1.5) and firm owners' optimal capital supply (1.17) gives

$$1 + \phi \left(\frac{K_{t+1}}{K_t} - 1 \right) = \beta \left(1 + \alpha z_{t+1} k_{t+1}^{\alpha-1} - \delta_k + \frac{\phi}{2} \left(\left(\frac{K_{t+2}}{K_{t+1}} \right)^2 - 1 \right) \right). \tag{1.18}$$

If capital adjustment costs are zero, (1.18) reduces to the condition that the inverse of the discount factor equals the net return on capital.

Wage Determination Many wages are consistent with an equilibrium in the search and matching labor market described so far. Therefore, I must take a stance on how the wage is determined. I assume that the wage in period t is a liner combination of the wage in the previous period and a target wage w_t^*,

$$w_t = \gamma w_{t-1} + (1 - \gamma) w_t^*. \tag{1.19}$$

For the theoretical results in Section 3, I assume that the target wage is simply a fixed fraction ω of match output,

$$w_t^* = \omega z_t k_t^\alpha. \tag{1.20}$$

I assume that ω is such that the wage lies in the bargaining set so that both workers and firms are wiling to sustain the match under the resulting wage. Instead, in the quantitative analysis, the target wage will be the result of Nash bargaining between workers and firms,

$$w_t^* = \arg\max_w \left(J_t(e,w) - J_t(u)\right)^\psi \left(J_t^F(w)\right)^{1-\psi}, \tag{1.21}$$

where ψ is the bargaining power of workers.[9]

The parameter γ in (1.19) governs the strength of wage inertia. Wages are completely fixed if $\gamma = 1$ and the wage always equals the target wage if $\gamma = 0$. The assumption of sticky wages is common in the literature at least since it was put forward by Hall (2005) as an empirically plausible way to resolve the observation by Shimer (2005) that the standard DMP model with Nash bargaining cannot easily generate the degree of counter-cyclicality of unemployment that is observed in the data. Hall (2003, 2005) also proposes the specific functional form (1.19) and provides a micro foundation for it. Pissarides (2009) challenges the view that wage stickiness can resolve the Shimer puzzle showing that only wages of new hires matter for the volatility of unemployment and that these exhibit much less inertia than wages at large. However, recent evidence by Gertler et al. (2020) indicates that wages in new matches are not as flexible as previously thought once composition effects are taken into account. This lends support to the assumption of wage stickiness.

Much of the literature that employs a DMP framework to study business cycles uses a slight simplification of the wage rule, in which the previous period's wage in equation (1.19) is replaced by the steady state wage (Blanchard and Galí 2010; Challe 2020). Such a rule removes the wage from the state space which would facilitate solving the model. However, it would not be appropriate for the purpose of this study. I am interested in the short-run effect of a *permanent* change of government investment and want the wage to adjust to the new environment in the long run. This is possible under my rule, but it would not be possible if the wage in the initial steady state was the wage norm.

2.3 Government

The government pays unemployment benefits b_t and makes investments I_t^G in public infrastructure. Public investment determines the public capital stock which follows the

---

[9] I have made explicit the dependence of the employed worker's value as well as the firm's value on the current wage w. In the definition of these value functions (1.11) and (1.4) the dependence on w was subsumed in the aggregate state of the economy indicated by the time subscript t.

law of motion

$$K^G_{t+1} = (1-\delta_G)K^G_t + I^G_t, \tag{1.22}$$

where δ_G is the depreciation rate of public capital. To finance its expenditures, the government collects lump-sum taxes on firm owners T^F_t and taxes labor income at rate τ_t.

The government's per-period budget constraint reads

$$I^G_t + U_t b_t = \mu T^F_t + \tau_t w_t N_t, \tag{1.23}$$

where U_t is the number of unemployed workers and $N_t = 1 - U_t$ is the number of employed workers in period t. The left-hand side of the government's budget constraint are government expenditures for public investment and unemployment benefits. The right-hand side captures total tax revenues.

Since I have discussed the most important equilibrium conditions already, I relegate a formal equilibrium definition to Appendix A.

3 Theoretical Analysis: Anticipation Effect on Labor Demand

In this section, I analyze the employment multiplier of public investment theoretically focusing on labor demand. I am interested in the change in employment in some period $t \geq 0$ that is brought about by a public investment program that is announced in period 0 and that permanently raises public investment starting in period $T \geq 0$. Hence, T denotes the implementation lag of public investment. Formally, I define the employment multiplier of public investment as follows.

Definition 1 (Employment multiplier of public investment). *Let* $N_t(\mathcal{X}_0, I^G_0, I^G_1, \dots)$ *denote employment in period t in an equilibrium with initial conditions* $\mathcal{X}_0 = (N_0, w_0, K^G_0, K_0)$ *and public investment sequence* $\mathcal{I}^G = \left(I^G_s\right)^\infty_{s=0}$. *Consider a permanent expansion in public investment starting in period T. The employment multiplier of public investment in t is*

$$M^{Inv}_t(T, \mathcal{X}_0, \mathcal{I}^G) = \frac{\partial N_T(\mathcal{X}_0, I^G_0, \dots, I^G_{T-1}, I^G_T + x, I^G_{T+1} + x, \dots)}{\partial x}|_{x=0}.$$

The employment multiplier tells us how much employment changes in period t when it is unexpectedly announced in period 0 that public investment will rise by 1 dollar in all periods after T. Figure 1.1 illustrates the employment multiplier of public investment graphically. The dots indicate the initial paths of public investment and employment, the crosses indicate the paths after the expansion of public investment. The difference between the two different employment paths at a given point t is the employment multiplier.

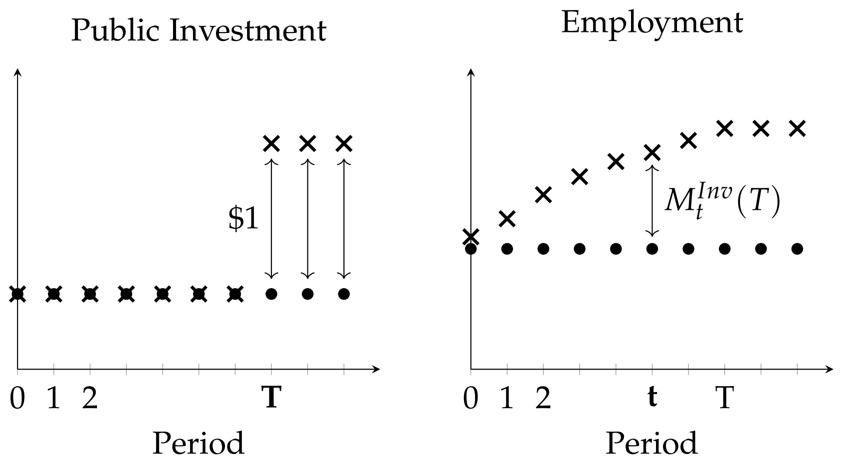


Figure 1.1: Graphical illustration of the employment multiplier of public investment
Notes: Dots indicate the initial paths of public investment and employment, crosses the paths after the policy change. $M_t^{Inv}(T)$ is the employment multiplier of public investment.

I make three assumptions.

Assumption 1. *Search effort is fixed at* $\ell_t(u) = 1$.

Hence, I focus on the role of labor demand for the employment multiplier of public investment. I allow for elastic search effort in the quantitative analysis in Section 5 and find that search effort contributes little to the employment effect.

Assumption 2. *The target wage is a fixed fraction of output and taken as given by firms, i.e., the target wage is given by* (1.20).

Assumption 2 implies that there is no feedback from vacancy posting to wages through Nash bargaining which simplifies the analysis. Given the optimal capital choice, the job creation equation (1.7), together with the law of motion for employment (1.13) and the accumulation equation of public capital (1.22), is then sufficient to characterize the employment multiplier.

Assumption 3. *Capital adjustment costs are zero,* $\phi = 0$.

This assumption simplifies the law of motion for capital as it eliminates the dependence of the optimal capital choice k_{t+1} on the current capital stock as well as on planned future capital. The choice for k_{t+1} then only depends on expected productivity in $t+1$ but not on past and future capital choices.

What happens to employment when the government announces a permanent expansion in public investment? Firms anticipate higher productivity in the future which increases the value of a filled vacancy but does not increase the cost of posting a vacancy. Therefore, firms post more vacancies and employment rises.

Importantly, the short-run employment effect is a dynamic phenomenon. Unless wages are completely rigid, public investment does not affect employment in the long run. The reason is that wages and posting costs grow in proportion to labor productivity in the long run. Hence, while output from a match is higher, so are all costs of the firm and the incentives to post vacancies are unchanged. Yet, employment still increases along the transition to the new steady state with high public investment. The reason is that hiring costs are fixed in the short-run whereas the return from a filled vacancy increases with future productivity. Proposition 1 formalizes these points.

Proposition 1 (Positive short-run employment multiplier of public investment)**.** *Suppose that* $I_t^G = \delta_G K_0^G$ *for all* $I_t^G \in \mathcal{I}^G$ *and that the initial wage is at least at the steady state level* $w_0 \geq \omega \left(\frac{\alpha\beta}{1-\beta(1-\delta_k)}\right)^{\frac{\alpha}{1-\alpha}} z^{\frac{1}{1-\alpha}}$. *Then, under assumptions 1–3, the employment multiplier of public investment is*

(i) positive, $M_t^{Inv}(T, \mathcal{X}_0, \mathcal{I}^G) > 0$,

(ii) zero in the long-run, $\lim_{t\to\infty} M_t^{Inv}(T, \mathcal{X}_0, \mathcal{I}^G) = 0$, *if wages are not completely rigid,* $\gamma < 1$.

Proof. See Appendix A.2. □

The employment multiplier can be characterized succinctly when the economy is in the steady state.

Proposition 2. *Suppose that the economy is in a steady state with* $I_t^G = \delta_G K^G$ *for all* $I_t^G \in \mathcal{I}^G$ *and assumptions 1–3 hold. Then, for* $t+1 \leq T$, *the employment multiplier of public investment is*

$$\begin{aligned} M_t^{Inv}(T, \mathcal{X}_0, \mathcal{I}^G) =& \vartheta \frac{(\beta(1-\rho))^{T+1-t}}{1-\beta(1-\delta_G)(1-\rho)} \frac{\delta_G}{I^G} \frac{1}{1-\alpha} \left[1 + \frac{\gamma\omega(1-\beta(1-\rho))}{(1-\beta\gamma(1-\rho))(1-\alpha-\omega)}\right] \\ & \times \frac{1-\eta}{\eta} U \pi^{e|u} \frac{1-((1-\rho-\pi^{e|u})\beta(1-\rho))^t}{1-((1-\rho-\pi^{e|u})\beta(1-\rho))} > 0 \end{aligned} \tag{1.24}$$

with $\pi^{e|u} = \zeta^{\frac{1}{\eta}} \left(\frac{\bar{\kappa}(1-\beta(1-\rho))}{\beta(1-\alpha-\omega)}\right)^{\frac{\eta-1}{\eta}}$.

Proof. See Appendix A.3. □

The proposition helps to understand the mechanism through which public investment affects employment in the short run and how the size of the employment multiplier depends on the fundamentals of the economy. Let us consider the employment multiplier in the first period, for $t = 1$. For this case, equation (1.24) reads

$$\begin{aligned} M_1^{Inv}(T, \mathcal{X}_0, \mathcal{I}^G) = {} & \overbrace{\frac{\vartheta\beta^T(1-\rho)^T}{1-(1-\delta_G)\beta(1-\rho)}\frac{\delta_G}{I^G}}^{\substack{\text{Semi-elasticity of match}\\ \text{productivity w.r.t. public}\\ \text{investment}}} \overbrace{\frac{1}{1-\alpha}}^{\substack{\text{Elasticity of}\\ \text{profits w.r.t.}\\ \text{productivity}}} \left[1+\overbrace{\frac{\gamma\omega(1-\beta(1-\rho))}{(1-\gamma\beta(1-\rho))(1-\alpha-\omega)}}^{\text{Wage stickiness}}\right] \\ & \times \frac{1-\eta}{\eta} U\pi(e|u). \end{aligned} \tag{1.25}$$

The first factor is the semi-elasticity of the present value of expected match productivity with respect to public investment,

$$\vartheta\frac{\beta^T(1-\rho)^T}{1-(1-\delta_G)\beta(1-\rho)}\frac{\delta_G}{I^G} = \frac{\partial\left(\sum_{s=1}^{\infty}\beta^s(1-\rho)^{s-1}z_s\right)}{\partial x}\frac{1}{\sum_{s=1}^{\infty}\beta^s(1-\rho)^{s-1}z_s}.$$

This is what drives the employment effect—public investment raises productivity over the expected course of a worker-firm match, which leads to vacancy creation by forward-looking firms. The productivity effect and thereby the employment multiplier are larger if the output elasticity of public capital, ϑ, is higher.

This may not seem surprising. If the output elasticity of public capital is larger, the future marginal product of labor and therefore future labor demand, labor market tightness and search costs increase more in response to an expansion in public investment. As a result, firms expand hiring by more already in the short run. Note that in a standard RBC model where labor demand is a static decision and public investment affects employment by shifting labor supply, a larger output elasticity of public capital can have the opposite effect (see Ramey 2020). The reason is that public investment raises household wealth relatively more if the output elasticity of public capital is higher. In the short run, this leads to a reduction in labor supply, hours worked and output compared to a case with a low output elasticity of public capital.

The remaining terms in the first line of equation (1.25) determine how match output translates into firm profits. This depends on $\frac{1}{1-\alpha}$, the elasticity of per-period firm profits with respect to instantaneous productivity under flexible wages and on the degree of wage stickiness captured by the term $\frac{\gamma\omega(1-\beta(1-\rho))}{(1-\gamma\beta(1-\rho))(1-\alpha-\omega)}$. The investment program has a stronger effect on employment if firm profits respond more strongly to changes in productivity, which is the case if α is larger and wages are more rigid.

Note that the wage stickiness term is zero if wages are fully flexible ($\gamma = 0$) but the employment multiplier is still strictly positive. Even if wages adjust to higher labor productivity immediately, an increase in expected future productivity raises the expected present value of output net of wages and of capital costs of a match, but it leaves the costs of posting a vacancy unchanged. This makes it more profitable for firms to post vacancies. Even though the employment multiplier is positive even when wages are flexible, it is larger if wages are more sticky. The reason is that for more rigid wages, an expected increase in future productivity does not translate into a proportional increase in wages immediately so that per-period profits from a filled vacancy are expected to increase temporarily.

Finally, the employment multiplier depends on how strongly employment responds to additional vacancy creation, which is determined by the term in the second line of equation (1.25). It depends on the elasticity of the matching function with respect to vacancies, $1 - \eta$, and on initial unemployment U. If the matching function elasticity is high, additional vacancies translate into relatively more matches and employment increases more strongly.

The discount factor and the separation rate affect the employment multiplier through two channels. First, they enter the first term in (1.25), the elasticity of match output with respect to public investment. Second, the discount factor and separation rate matter for the employment multiplier because they determine the importance of wage stickiness.

Suppose first, that there is no wage stickiness, $\gamma = 0$. In this case, a higher discount factor and a lower separation rate unambiguously increase the employment effect as both facilitate labor hoarding. When the discount factor is higher, firms value the increase in productivity in the (distant) future relatively more compared to additional costs of hiring and hoarding labor that are incurred in the near future. Hence, the employment effect of public investment is larger. If the separation rate is low, it is more likely that workers hired today will remain with the firm in the future. This makes it easier to substitute hiring inter-temporarily when future costs of filling a vacancy increase as a result of tighter labor markets. This leads to a larger employment effect.

When wages are sticky, there is an opposing channel through which the discount factor and the separation rate affect the employment multiplier. A higher discount factor as well as a lower separation rate reduce the term labeled "Wage stickiness" in (1.25) leading to a smaller employment multiplier. When wages are sticky, they remain low initially after the expansion in public investment such that profits increase more strongly at first. However, wages adjust to higher levels of productivity and lower the profit margin over time. In the long run, profits are unaffected by wage stickiness. When the separation rate is low or the discount factor is high, profits in the distant future are relatively more important for the total surplus from a filled vacancy. Hence, the fact that wages remain low initially is relatively unimportant for firms vacancy creation decision. This is why, higher discount factors and lower separation rates can lead to less vacancy creation in response to an expansion in public investment. When wages are completely rigid ($\gamma = 1$) the discount factor and separation rate cancel out in the wage stickiness term. In this case, wages never adjust to higher productivity and the relative importance of wage payments in the distant future does not affect the present value of expected profits and vacancy creation. For the intermediate case with some wage stickiness, the overall effect of discount factor and separation rate on the employment effect of public investment is theoretically ambiguous. Quantitative analyses suggest that the employment effect increases with the discount factor and declines with the separation rate.

The change in employment at a given point in time declines with the implementation lag T. If the implementations lag is long, firms expect productivity to increase only in the very distant future and the program has a relatively small effect on employment in the near future. For a given steady state job finding probability $\pi^{e|u}$, the degree to which the implementation lag matters depends on the discount factor β and the separation rate ρ.

Proposition 2 also shows that the employment multiplier increases in t, the time since the investment program has become known. The reason is twofold: First, as t increases the increase in productivity comes closer which raises the value of a filled vacancy and leads to more hiring. Second, if t is larger, more time has passed since news about higher future productivity became known such that firms' expansion in hiring has had more time to reduce unemployment.

3.1 Business cycle dependence of employment multiplier

Are the employment effects of public investment different if the government announces the expansion in public investment during a recession? To shed light on this question, I investigate how the employment multiplier depends on two defining features of recessions, high unemployment and temporarily weak labor demand.

The law of motion for employment (1.13) helps to understand how unemployment influences the employment effect of public investment. I restate it here for convenience

$$N_{t+1} = (1-\rho)N_t + \pi_t^{e|u}(\theta_t)U_t.$$

Public investment induces an increase of labor market tightness and of the individual job finding probability of unemployed workers, $\pi_t^{e|u}(\theta_t)$. As can be seen from the law of motion for employment, if the number of unemployed workers is larger, a given increase in the job finding probability benefits more workers and aggregate employment increases more strongly.

An alternative intuition that helps to understand the effect of unemployment on the employment multiplier comes from firms' vacancy creation. When unemployment is high, an additional vacancy has only a small effect on the vacancy filling probability of other firms. Suppose for example, that labor market tightness is one, i.e., there is one vacancy for every unemployed worker. If there is only one unemployed worker, an additional vacancy doubles labor market tightness. In contrast, if there are ten unemployed workers, an additional vacancy increases labor market tightness only by 10%. In the second case, the additional vacancy will have a much smaller effect on the expected costs of all other firms to fill a vacancy than in the first case; the congestion externality is small when unemployment is high. Hence, vacancy creation expands more in response to an increase in public investment that raises future productivity, and the employment multiplier of public investment is larger when unemployment is high.

A second feature of recessions that is important for the short-run employment effect of public investment is weak labor demand, i.e., low labor market tightness and a small job-finding probability of unemployed workers. In the model, labor demand is low if the wage is high relative to productivity. Thus, I study how the short-run employment effect of public investment depends on the wage relative to productivity. To develop the main intuition, consider the job creation equation (1.7) in period 0. It can be written as

$$\frac{\kappa_0}{q^v(\theta_0)} = \beta(y_1 - w_1 + (1-\rho)J_2^F), \tag{1.26}$$

where y_1 is labor productivity in period 1 and w_1 is the wage in period 1. The variable J_2^F is the value of a filled vacancy in period 2. For now, I interpret period 2 as the long run and I suppose that public investment raises the value of a match in the long run $\mathrm{d}J_2^F > 0$. The job creation equation yields

$$\mathrm{d}q^v(\theta_0) = -\frac{\beta(1-\rho)}{\kappa_0} q^v(\theta_0)^2 \mathrm{d}J_2^F = -\frac{(1-\rho)\kappa_0}{\beta(y_1 - w_1 + (1-\rho)J_2^F)^2}\mathrm{d}J_2^F < 0.$$

As can be seen from the first equality, the vacancy filling probability declines relatively more if labor market tightness is low and the vacancy filling probability, $q^v(\theta_0)^2$, is high, i.e., if labor demand is weak. This is the case if the wage, w_1, is high relative to labor productivity, y_1, such that the value of a match is relatively small. In this case, the same increase in the long-run value of a match leads to a relatively larger effect on the total value of a match and thereby on the vacancy filling probability.

The corresponding change of the job-finding probability in response to an increase in the long run value of a match is

$$\mathrm{d}\pi_0^{e|u}(\theta_0) = \mathrm{d}q^v(\theta_0)\theta_0 = q^{v\prime}(\theta_0)\theta_0\mathrm{d}\theta_0 + q^v(\theta_0)\mathrm{d}\theta_0 = \frac{\eta-1}{\eta}\theta_0\mathrm{d}q^v(\theta_0) > 0.$$

We know from above that the change in the job finding probability, $\mathrm{d}q^v(\theta_0)$, is larger when labor demand is weak. But labor market tightness is lower, too, which has a negative effect on the employment multiplier. This is because, for a given level of unemployment, the same relative increase in labor market tightness corresponds to relatively few additional vacancies when labor market tightness is low.

Overall, the effect of weaker labor demand on the job finding probability is theoretically ambiguous, it depends on the elasticity of the matching function with respect to vacancies.

The next proposition shows that these intuitions carry over to the full model.

Proposition 3 (Business cycle dependence of employment effect)**.** *Suppose that* $I_t^G = \delta_G K_0^G$ *for all* $I_t^G \in \mathcal{I}^G$ *and that the wage is at the steady state level* $w_0 = \omega \left(\frac{\alpha\beta}{1-\beta(1-\delta_k)} \right)^{\frac{\alpha}{1-\alpha}} z^{\frac{1}{1-\alpha}}$. *If assumptions 1–3 hold, then, for* $t+1 \leq T$*, the employment multiplier of public investment is*

- *(i) increasing in initial unemployment,* $\frac{\partial M_t^{Inv}(T,\mathcal{X}_0,\mathcal{I}^G)}{\partial U_0} > 0$
- *(ii) increasing in the initial wage* $\frac{\partial M_t^{Inv}(T,\mathcal{X}_0,\mathcal{I}^G)}{\partial w_0} \geq 0$ *if* $\eta > 0.5$.

Proof. See Appendix A.4. □

3.2 Welfare effects of public investment

The permanent expansion in public investment raises employment as firms expand hiring in anticipation of higher future productivity. I now show that this increase in employment constitutes an efficiency gain when equilibrium labor demand is inefficiently low. In this case, public investment improves labor market efficiency because the anticipation effect stimulates labor demand and brings vacancy creation closer to its efficient level. Therefore, public investment has a positive effect on welfare beyond the return from public investment and redistribution.

I define social welfare as follows

$$W(\{c_t^F, c_t(s^t), \ell_t(s^t)\}) = \bar{\mu}^F \sum_{t=0}^{\infty} \beta^t u^F(c_t^F) + \sum_{t=0}^{\infty} \beta^t \sum_{s^t} u\left(c_t(s^t), \ell_t(s^t), s_t\right) \pi_t(s^t|s_0) \bar{\mu}(s_0).$$

Here, $\bar{\mu}^F$, $\bar{\mu}(e)$ and $\bar{\mu}(u)$ are the welfare weights of firm owners, initially employed and initially unemployed workers and $\pi_t(s^t|s_0)$ denotes the share of workers with history $s^t = (s_0, s_1, \ldots, s_t)$ in period t. Let C_t denote aggregate consumption in period t and define the consumption shares of individual firm owners and of workers as $v_t^F \equiv \frac{c_t^F}{C_t}$ and $v_t(s^t) \equiv \frac{c_t(s^t)}{C_t}$.

Under Assumption 1 (fixed search effort), the effect of the investment program on welfare is

$$\begin{aligned} \frac{\partial W}{\partial x} = & \underbrace{\sum_{t=0}^{\infty} \beta^t C_t \left(\bar{\mu}^F u_c^F(c_t^F) \frac{\partial v_t^F}{\partial x} + \sum_{s^t} \bar{\mu}(s_0) \pi_t(s^t|s_0) u_c(c_t(s^t)) \frac{\partial v_t(s^t)}{\partial x} \right)}_{\text{redistribution (intensive margin)}} \\ & + \underbrace{\sum_{t=0}^{\infty} \beta^t u(c_t(s^t), \ell_t(s^t), s_t) \bar{\mu}(s_0) \frac{\partial \pi_t(s^t|s_0)}{\partial x}}_{\text{redistribution (extensive margin)}} + \underbrace{\sum_{t=0}^{\infty} \beta^t \mathrm{m}_t \frac{\partial C_t}{\partial x},}_{\text{aggregate consumption}} \quad . \end{aligned} \tag{1.27}$$

Here,

$$\mathrm{m}_t \equiv \bar{\mu}^F v_t^F u_c^F(c_t^F) + \sum_{s^t} \bar{\mu}(s_0) \pi_t(s^t|s_0) v_t(s^t) u_c(c_t(s^t)) \tag{1.28}$$

is the marginal utility of aggregate consumption in period t, a weighted average of individual marginal utilities of consumption, where the weight of each agent corresponds to its welfare weight multiplied by its consumption share.

As can be seen from equation (1.27), the effect of the expansion in public investment on welfare can be decomposed into three parts. The first captures the effect of public investment on the distribution of consumption along the intensive margin. Depending on how the increase in public investment is financed, consumption of employed workers, unemployed workers or firm owners increases or falls relative to aggregate consumption and this redistribution changes welfare, even if aggregate consumption remains unchanged. This distributive effect is captured by the first line in equation (1.27). Note that under Assumption 2 wages are independent of taxes such that the government can use labor taxes and lump-sum taxes on firm owners to finance investment in a way that leaves the consumption shares of all households unchanged. In this case there is no redistribution of consumption along the intensive margin and the first line in (1.27) is zero.

The second effect on welfare emerges because the increase in public investment redistributes consumption (and effort) along the extensive margin as it alters the share of workers who are employed. Proposition 1 showed that employment increases in all periods in response to a permanent expansion in public investment if the wage and public investment are in steady state initially. Hence, the extensive margin redistribution raises welfare for sensible parameter choices under which the after-tax wage exceeds unemployment benefits and compensates for potential utility losses from working.

The last summand in equation (1.27) captures the welfare effect of changes in aggregate consumption due to a permanent increase in public investment. The change in aggregate consumption is

$$\sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \frac{\partial C_t}{\partial x} = \underbrace{\sum_{t=0}^{\infty}\beta^t \mathrm{m}_t K_t^{\alpha} N_t^{1-\alpha}\frac{\partial z_t}{\partial x}}_{\text{direct gross return}} - \underbrace{\sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \frac{\partial I_t^G}{\partial x}}_{\text{costs}} + \underbrace{\sum_{t=0}^{\infty}\beta^t \mathrm{m}_t EG_t}_{\text{efficiency gain}} \tag{1.29}$$

Equation (1.29) shows that there are three channels through which the permanent increase in public investment affects aggregate consumption. The first two are standard. On the one hand, public investment raises productivity, which leads to an increase in output and consumption. On the other hand, there is a resource cost of public investment that reduces consumption. In the frictional labor market considered here, there is a third channel through which public investment affects output. I label it EG_t for "Efficiency Gain" in equation (1.29).

If the economy is in the steady state, the efficiency gain is

$$\sum_{t=0}^{\infty}\beta^t \mathrm{m}_t EG_t = \frac{1}{1-\eta}\left[w-\eta\left((1-\alpha)zk^{\alpha}+\theta\kappa\right)\right]\sum_{t=0}^{\infty}\beta^t m_t M_{t+1}^{Inv}.$$

It comes from the fact that the equilibrium in the matching labor market is not necessarily efficient such that the employment effect of public investment by itself can improve welfare.[10] When a firm posts a vacancy, it imposes a negative externality on other firms, since the additional vacancy makes it more difficult for other firms to fill theirs. However, there is also a positive externality because every additional vacancy makes it easier for workers to find a job. As shown by Hosios (1990), there exists a wage that internalizes both effects and leads to the optimal level of vacancy creation. This wage is such that workers' share of the total match surplus equals the elasticity of the matching function. Here, this is the case if

$$w^* = \eta \left((1-\alpha) z k^{\alpha} + \theta \kappa \right).$$

I show this formally in Appendix C.2, where I derive the constrained efficient allocation. When the equilibrium wage equals the efficient wage, $w = w^*$, the efficiency gain is zero. In contrast, if the wage exceeds the efficient wage, $w > w^*$, vacancy creation in equilibrium is too low and the expansion in labor demand brought about by the investment program can raise the amount of resources available for consumption. The following proposition summarizes this result.

Proposition 4 (Efficiency gains from public investment)**.** *Suppose the economy is in a steady state with inefficiently low labor demand,* $w > w^*$*. Then, the public investment program improves labor market efficiency,* $\sum_{t=0}^{\infty} \beta^t \mathrm{m}_t EG_t > 0$.

Proof. See Appendix A.5. □

A similar result can be found in the online appendix of Den Haan and Kaltenbrunner (2009) who study a simplified two-period DMP model. They find that news about future productivity can lead to a resource gain when the Hosios condition is violated.

4 Calibration

To quantify the employment effect, I calibrate the model to the US economy. I choose a period length of one month. The calibration targets the steady state of the model. However, two parameters are irrelevant for the steady state, the degree of wage stickiness, γ, and ϕ, which governs the capital adjustment costs. For these two parameters, I pick values previously used in the literature and validate this choice by comparing the business cycle moments generated by the model to those in the data.

Technology Regarding the production technology, I set $\alpha = 0.33$ and assume the monthly depreciation rate of physical capital is $\delta_k = 0.00874$, which corresponds to

---

[10] For simplicity, I assume that vacancy posting costs are constant, $\kappa_t = \kappa$. In Appendix A.5, I characterize the effect of public investment on aggregate consumption also for the general case in which posting costs can depend on public investment.

10% annually. Following Baxter and King (1993), the depreciation rate of public capital is also set to $\delta_G = 0.00874$. Regarding the elasticity of productivity with respect to public capital, ϑ, the meta study by Bom and Ligthart (2014) points to an elasticity of 0.12 in the long-run, Bouakez et al. (2017) find 0.065 and Cubas (2020) finds 0.09. I decide on an intermediate value of 0.1 which is also considered in Leeper et al. (2010) and Leduc and Wilson (2013).[11] This is a conservative choice, other empirical studies have found substantially larger values than those above. For example, Aschauer (1989) finds 0.39 and Pereira and Frutos (1999) report 0.63 as a general equilibrium elasticity which according to Ramey (2020) corresponds to a value for ϑ of 0.39. Finally, I set A to normalize labor productivity to one, $(1-\alpha)zk^{\alpha} = 1$, at a public investment rate of 2.9%, the average rate for the US between 1990 and 2019.

Government I set the public investment rate to 2.9%, the average rate for the US between 1990 and 2019 and the labor tax rate τ to 30%, as commonly done for the US. I assume that unemployment benefits are proportional to the net wage, $b_t = \bar{b}(1-\tau_t)w_t$, and set the replacement rate $\bar{b}$ to 70%. This is higher than the average replacement rate in the US, usually found to be close to 40%. However, it implies a decline in consumption expenditures upon becoming unemployed close to the estimates of Chodorow-Reich and Karabarbounis (2016) from the Consumer Expenditure Survey, which lie between 28% for food, clothing, recreation and vacation and 21% for food. Lump-sum transfers to firm owners are then chosen to ensure a balanced government budget.

Labor market The calibration approach for the parameters related to the labor market is standard in the literature and follows Shimer (2005). In particular, I match the transition probabilities between employment and unemployment.

In order to estimate these transition probabilities from CPS microdata, I need a definition of unemployment in the data that most closely corresponds to unemployment in the model. Most of the literature uses the unemployment concept U-3 of the Bureau of Labor Statistics (BLS) which defines unemployed workers as those who are not employed, but available to work, and made an effort to find work during the last four weeks or were temporarily laid off and waiting to be recalled. In the model, all workers who are not employed are considered unemployed irrespective of how intensely they search. Therefore, I use a broader definition of unemployment for the baseline calibration, which also encompasses marginally attached workers. These are workers who are not employed but available to work, state that they want a job and have searched for a job during the last twelve months. Hence, I use the unemployment concept U-5 of the BLS. However, I obtain very similar results when I calibrate the model using U-3 unemployment instead.

---

[11] In addition to $\vartheta = 0.1$, Leeper et al. (2010) also consider $\vartheta = 0.05$.

I match individuals over time in CPS microdata from January 1994 to December 2020 to estimate monthly job finding probabilities and separation probabilities from gross flows between labor market states. The estimation approach follows Shimer (2012) and is described in greater detail in Appendix B.1. Table 1.B1 gives an overview of the estimation results.

I find a monthly separation probability of 1.9% which directly informs the choice of the separation parameter ρ. It implies that jobs last about 52 months on average. Hagedorn and Manovskii (2008) use a slightly higher but comparable number of 2.6% that leads to an average job duration of 38 months. The parameter ρ is crucial for the size of the employment effect as it determines how long firms can expect a match to last (see Proposition 2). In the model, the rate at which matches are dissolved equals the rate at which workers become unemployed or leave the labor force, but this need not be the case if there are job-to-job transitions. However, Hyatt and Spletzer (2016) document that average tenure has risen since the 1980s and median job tenure of employed workers was around 4.5 years in 2012, even longer than the median tenure of about three years implied by my choice for ρ.

For the monthly job finding probability I estimate a value of 26.9%. In contrast to the separation probability, the job finding probability $\pi_t^{e|u}$ is determined endogenously in the model and I match the estimated value by choosing the remaining labor market parameters as follows.

I set the elasticity of the matching function with respect to unemployment to $\eta = 0.3$. This is on the lower end of the range of empirical estimates surveyed in Petrongolo and Pissarides (2001) but still larger than 0.245 chosen in Hall (2005).

I chose a value of $\psi = 0.4016$ for workers' bargaining weight in order to match a labor share of 64%. In Appendix D.2, I alternatively calibrate the bargaining power such that the steady state wage is efficient.

Den Haan et al. (2000) find a vacancy filling probability of $q^v = 71\%$. According to the job creation equation (1.7), this requires $\bar{\kappa} = 0.8187$. It remains to calibrate the matching efficiency ζ and the disutility from effort. Regarding the latter, I assume that $d(\ell, s) = d_1 \frac{\ell^{1+\chi}}{1+\chi} + d_{0,s}$ as in Krebs and Scheffel (2017). I set $d_{0,u} = 0$ as a normalization and choose $d_{0,e}$ such that in the steady state there is no difference between the disutility from working and searching. This means that search effort and other non-pecuniary costs of unemployment such as lower social status offset the utility gain from more leisure, an assumption also made in McKay and Reis (2021). The matching efficiency ζ and the disutility parameter d_1 are not separately identified which is why I normalize $d_1 = 1$. I then choose $\chi = 5.6073$ to obtain a micro elasticity of the job finding probability with respect to unemployment benefits of –0.5.[12] This elasticity is in line with direct empirical evidence in Chetty (2008) who obtains an estimate of –0.53. It is also in the range from

---

[12] See Appendix B.2 for a derivation of χ in terms of the micro elasticity of the job finding probability with respect to unemployment benefits.

–0.6 to –0.2 considered in Landais et al. (2018). I set $\zeta = 0.5584$ to match my estimate for the monthly job finding probability of 26.9%. More specifically, the target for the job finding probability $\pi^{e|u} = 0.269$ together with a vacancy filling probability of $q^v = 0.71$ implies that $\theta\ell(u) = \frac{0.269}{0.71} = 0.379$. For the parameters calibrated so far, search effort is $\ell(u) = 0.84$ such that $\theta = 0.45$. Since $q^v = \zeta\theta^{-\eta}$, I get $\zeta = 0.5584$.

Discount factor I calibrate the discount factor such that the assumed hand-to-mouth behavior of workers is optimal in an extended model where workers can save in a risk-free bond. In Appendix C.1, I describe the extended model and show that workers are hand-to-mouth if the interest rate on the bond is at most

$$1 + r_{t+1} = \frac{1}{\beta}\left(\left[\pi_t^{e|e}\frac{(1-\tau_t)w_t}{(1-\tau_{t+1})w_{t+1}}\varphi_{t+1} + \pi_t^{u|e}\frac{(1-\tau_t)w_t}{b_{t+1}}\right]\right)^{-1} \tag{1.30}$$

with

$$\varphi_t = 1 - (1-\gamma)(1-\psi)\frac{1 - \frac{w_t^N}{b_t} + J_t(e) - J_t(u)}{1 + (1-\psi)\left(J_t(e) - J_t(u)\right)}. \tag{1.31}$$

I set the monthly discount factor to $\beta = 0.9930$ to obtain an annual interest rate of 1% according to equation (1.30).[13] Note that with $\varphi_{t+1} = 1$ the right-hand side of (1.30) is the standard formula for the intertemporal marginal rate of substitution between consumption today and tomorrow. The term φ_{t+1} captures an additional savings motive which arises because asset holdings affect the bargaining position of workers. Inspection of (1.31) shows that this motive is absent if wages are completely rigid ($\gamma = 1$) or if workers have the entire bargaining weight so that they receive the total surplus regardless of their asset holdings ($\psi = 1$).[14] Due to the precautionary savings motive and the effect of savings on the bargaining position, the discount factor is lower than under complete markets which leads to a relatively smaller employment effect (see the discussion in the previous section).

Table 1.1 provides an overview of the calibrated parameters. In the steady state, the unemployment rate is 6.58%. For comparison, the average U-5 unemployment rate from 1994 to 2020 was 6.86%. The (private) physical investment rate is 18.7%, close to the average of 17.3% observed in the data since 1990.[15]

Finally, I set the parameter γ, which governs the extent of wage stickiness, to 0.993. This choice is also considered in Shimer (2010) who argues that it leads to a reasonable volatility of unemployment over the business cycle. I pick $\phi = 15$ for the capital adjustment cost parameter. As shown in the next subsection, for these choices, the model is able to replicate the volatility of unemployment and investment observed in the data for

---

[13] Note that since workers face unemployment risk and firm owners do not, workers always have a higher willingness to save for a given discount factor.

[14] See Krusell et al. (2010) for a detailed investigation of this effect on savings and the labor market.

[15] The investment rate has not changed much over time, averaging at 17.1% for the time since 1947.

Table 1.1: Baseline calibration.

Parameter		Value	Description	Target or source
Technology	ϑ	0.10	output elasticity public capital	see text
	α	0.33	output elasticity private capital	standard
	δ_G	0.0087	public capital depreciation	depreciation 10.0% p.a.
	δ_k	0.0087	private capital depreciation	depreciation 10.0% p.a.
	A	0.3576	productivity	labor productivity normalized to 1
	ϕ	15	capital adjustment costs	see text
Labor market	η	0.3	matching function elasticity	Petrongolo and Pissarides (2001)
	ψ	0.4016	worker bargaining weight	labor share 64.0%
	ρ	0.0189	separation probability	1.9% (own estimate)
	ζ	0.5584	matching efficiency	vacancy filling prob. 71.0% (HRW00)
	$\bar{\kappa}$	0.8187	posting costs (labor)	job-finding prob. 26.9% (own est.)
	γ	0.9930	wage stickiness	see text
Preferences	β	0.9930	discount factor	interest rate 1.0% p.a.
	χ	5.6073	search elasticity	$\mathrm{d}\log q^f/\mathrm{d}\log b = -0.5$
	$d_{0,e}$	0.0492	disutility from working	$d(\ell(u), u) = d(0, e)$
Government	τ	0.3	labor tax rate	standard
	$\bar{b}$	0.7	wage replacement rate	see text
	I^G/Y	0.029	public investment rate	average 1990–2019

Notes: HRW00 stands for Den Haan et al. (2000).

a realistic process of productivity. In the appendix, I investigate the role of wage stickiness γ and capital adjustment costs ϕ for the size of the employment multiplier (Figures 1.D10 and 1.D9).

4.1 Business cycle properties

I compute standard deviation and quarterly autocorrelation of unemployment, output, investment, and labor productivity in the data to evaluate the model's ability to match the volatility and persistence of these variables. To be precise, I compute these moments for the relative deviations from a long-run trend obtained using an HP filter with smoothing parameter 1,600. I use data from the first quarter of 1951 to the fourth quarter of 2019. All moments shown in the first two rows of Table 1.2 are close to those found in the literature. In particular, the estimates of the standard deviation and autocorrelation of the U-3 unemployment rate are very close to those in Hagedorn and Manovskii (2008) who report 0.125 and 0.870, respectively. Since the calibration focuses on the broader measure of U-5 unemployment, I also report the respective moments for this variable. Relative to U-3 unemployment, it exhibits a slightly lower standard deviation of 0.101 and a higher autocorrelation of 0.943. Standard deviation and autocorrelation of labor productivity are also very close to the estimates in Hagedorn and Manovskii (2008) who find 0.013 and 0.765.

In order to assess the model's ability to replicate these moments, I assume that the

Table 1.2: Overview of business cycle moments

		U-5	U-3	Y	Inv	Wages	Lab. prod.	z
Data	Std. dev.	0.101	0.128	0.015	0.065	0.010	0.012	0.012
	Autocorr.	0.943	0.886	0.845	0.821	0.744	0.761	0.797
Model	Std. dev.	0.081	–	0.017	0.090	0.008	0.011	0.012
	Autocorr.	0.848	–	0.846	0.248	0.947	0.789	0.791

Notes: For comparability with the data, all model moments are computed for the relative deviations from the HP trend of the series aggregated to quarterly frequency. I use quarterly data from 1951:I to 2019:IV.

public capital stock is constant and A_t follows an AR(1) process in logs

$$\log A_t = \rho \log A_{t-1} + \nu_t, \tag{1.32}$$

where ν_t is normally distributed with mean zero and standard deviation σ_ν. For the baseline calibration, I set $\rho = 0.9870$ and $\sigma_\nu = 0.0054$. This way, standard deviation and autocorrelation of quarterly TFP in the model match those in the data. Here, I fix unemployment benefits at the steady state level. In reality, benefits depend on the individual labor market history. Thus, benefits grow with wages in the long run which is why I assume that benefits are proportional to wages in the next section, when I investigate the employment effects of a permanent expansion in public investment Here, I only consider short-run fluctuations, so that a constant level of benefits is a good approximation to observed benefit schemes. However, the results are very similar when I assume that benefits are proportional to wages.

The last two rows of Table 1.2 show the model moments corresponding to those in the data. Importantly, the volatility of unemployment and output are close to the data, although the volatility of unemployment is still slightly lower than observed in the data. As pointed out by Shimer (2005), it is generally difficult for the DMP model to match the volatility of unemployment. My model is able to generate a volatility similar to the data mainly because of the relatively high degree of wage inertia. Nevertheless, the volatility of wages in the model is only slightly lower than in the data. Despite the capital adjustment costs, the volatility of private investment is still larger in the model than in the data, but the order of magnitude is the same. Table 1.D2 in the appendix shows that the model also matches the cross-correlations between the variables reasonably well, only the correlation between productivity and wages is too high.

5 Quantitative Analysis of the Employment Effect

I assume that the government announces a permanent expansion in government investment by 1% of GDP in period zero. The program is financed with lump-sum taxes on firm owners. In the long run, the program increases the public capital stock and thereby raises private factor productivity (z_t) by 3%.

Figure 1.2 shows the responses of key variables to the announcement of the government investment program. I assume that the economy is in its steady state initially and consider the response over the first two years.[16] The solid blue lines depict the baseline scenario in which public investment increases at the same time the program is announced such that private productivity starts to rise in the first period.

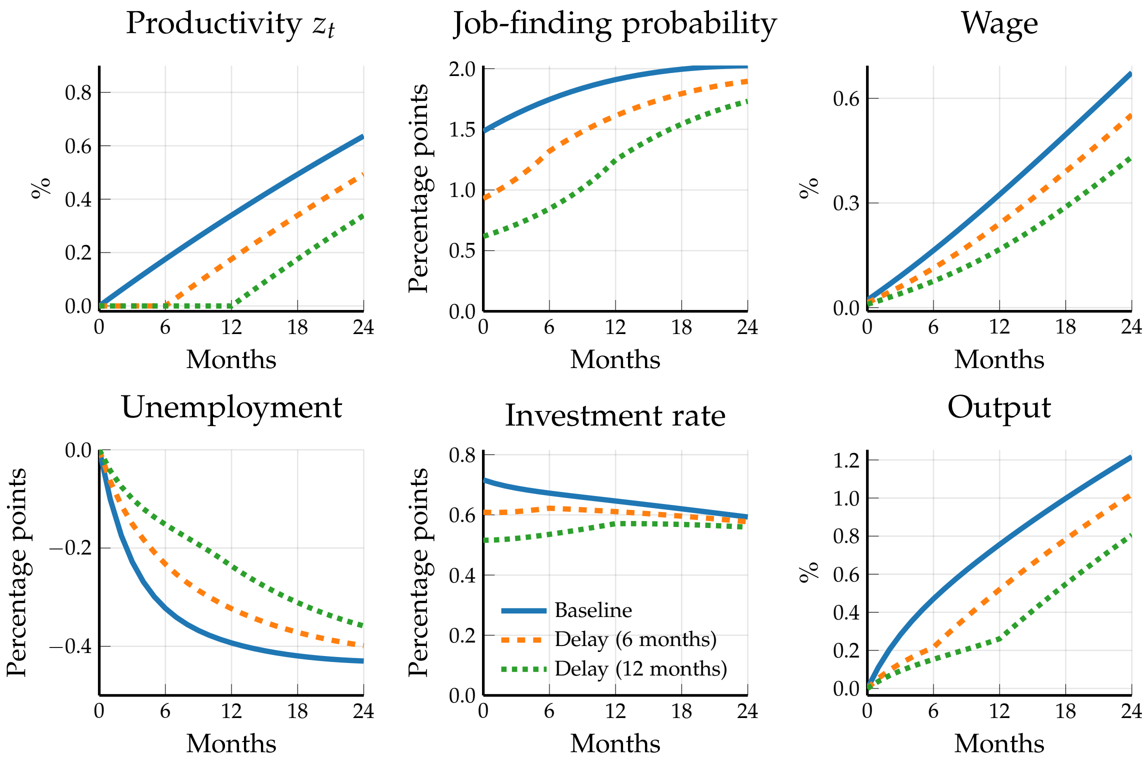


Figure 1.2: Short-run responses to public investment program.

Notes: The figure shows the responses to a permanent expansion of public investment by 1% of initial GDP for different implementation delays as deviations from the initial steady state.

Productivity of private factors increases almost linearly over the first two years of the program after which it is 0.63 percent higher than before. The increase in productivity brought about by public investment has a substantial effect on unemployment and output. With the start of the program, firms expand vacancy creation such that the job finding probability increases by 1.5 percentage points on impact. The increase in the job finding probability lowers the unemployment rate by 0.4 percentage points after twelve months. The private investment rate increases by about 0.7 percentage points on impact and then quickly returns to a permanently elevated level 0.6 percentage points above the one that would be seen without the investment program. As a consequence of higher productivity, increased hiring, and private investment, output is about 0.8% higher after one year.

---

[16] See Figures 1.D4 and 1.D3 in the appendix for the long-run responses and the corresponding fiscal policy.

Table 1.3: Employment multipliers after one year for different scenarios, jobs created per $ millions public investment.

Baseline	Recession	Delay 6 months	Delay 12 months	Labor tax financed
2.49	3.06	2.02	1.43	1.11

Notes: The table shows the number of additional jobs created for every million of dollars in additional, permanent yearly public investment.

Wages also increase substantially and are 0.32% percent higher after one year than they would have been without additional public investment. This might be surprising at first given the seemingly high degree of wage inertia with $\gamma = 0.993$. The reason that wages still respond relatively strongly is that the higher job finding probability improves the bargaining position of workers such that the Nash bargaining wage increases substantially (see Figure 1.5 and the discussion below). During the first years after the start of the program, the Nash wage exceeds the new long-run wage, which leads to a much faster increase of the wage than would be obtained if I naively substituted the new long-run Nash wage into the wage rule and iterated forward.[17]

The first column of Table 1.3 shows the corresponding employment multiplier of public investment as defined in Section 3. It amounts to 2.5 additional jobs created per million dollars of yearly public investment. The multiplier may appear small compared to recent empirical estimates of the multiplier of overall government spending, for example in Chodorow-Reich et al. (2012), Wilson (2012), and Serrato and Wingender (2016) who find employment multipliers of government spending between 8 and 38 jobs per one million in spending. This comparison is misleading for two reasons. First, the empirical estimates do not account for the quality of the job such that the additional jobs might be primarily low-paying jobs. For example, the estimated local income multiplier in Serrato and Wingender (2016) is 1.7 to 2, which is much less than the one that would be obtained if every created job paid the average wage. In contrast, jobs are homogeneous in my model such that the newly created jobs pay the average wage. Second, the papers cited above estimate "local" multipliers which may be very different from aggregate multipliers (Ramey 2011). "Local" multipliers do not capture the general equilibrium effects associated with a nationwide expansion in public spending, which could dampen the employment effects. Aggregate-level estimates of government spending on employment that account for general equilibrium effects are rare.

Monacelli et al. (2010) find that additional spending of 1% of GDP lowers unemployment by 0.43 percentage points after one year, almost identical to the effect of public investment I find. This is despite the fact that my model does not feature amplification effects through aggregate demand. Neither the public investment spending itself

---

[17] Compare the discussion in Hall (2003, Section V.C).

Table 1.4: Output multipliers of public investment at different horizons.

	1 year	2 years	3 years	Long run
Peak	0.71	1.18	1.57	4.52
Cumulative	0.41	0.69	0.93	4.52

Notes: The peak multiplier is the maximum change in output divided by the change in public investment over the respective horizon H, $\max_{h \leq H} \frac{\Delta Y_h}{\Delta I_h^G}$. The cumulative multiplier is the cumulative change in output over horizon H divided by the cumulative change in public investment over the same horizon, $\frac{\sum_{h \leq H} \Delta Y_h}{\sum_{h \leq H} \Delta I_h^G}$.

nor higher consumption demand of workers due to improved labor market conditions stimulate aggregate output. If output was partially demand determined instead, the employment multiplier of public investment would likely be even larger. Indeed, the interest rate in an extended model with a consumption savings decision of workers (see Appendix C.1) increases in response to the expansion in public investment which indicates an increase in aggregate private consumption demand.

The employment multiplier of unproductive spending (i.e., government consumption) is zero in the baseline scenario, in which spending is financed with lump-sum taxes on firm owners, because government spending crowds out consumption of firm owners one for one.[18] Hence, the multiplier of public investment here also measures the extent to which the employment effect of public investment exceeds the effect of unproductive government consumption. Interpreted this way, an excess multiplier of public investment over government consumption of 2.49 jobs per million dollars is large.

Table 1.4 shows, at different horizons, the output multipliers associated with the expansion of public investment. The first row displays the peak multiplier, the maximum change in output divided by the change in public investment over the respective horizon, $\max_{h \leq H} \Delta Y_h / \Delta I_h^G$. The second row is the cumulative multiplier, the cumulative output change divided by the cumulative change in public investment, $\sum_{h \leq H} \Delta Y_h / \sum_{h \leq H} \Delta I_h^G$. The table shows that the anticipation effect of public investment, without additional amplification through aggregate demand, already leads to output multipliers in the range of empirical estimates of overall government spending multipliers (Ramey 2011). Multipliers increase over time, as both the employment effects and the productivity effects of public investment take time to materialize. This is also why the peak multipliers in the short run are generally larger than the cumulative multipliers.

It is instructive to compare the short-run responses to the long-run effect of the in-

---

[18] The employment multiplier of unproductive spending would even be negative if government consumption was financed with distortionary labor taxes. Financing with lump-sum taxes on workers (employed and unemployed) would lead to positive but very small employment effects of government consumption.

crease in public investment shown in Figure 1.3. As stated in proposition 1, the investment program does not affect unemployment in the long run. This is because, in the long run, vacancy posting costs, wages, and unemployment benefits are all proportional to labor productivity. As a result, higher productivity does not affect firms' incentives to post vacancies in the long run. Since workers have logarithmic utility, the constant wage replacement rate of unemployment benefits implies that workers' search effort is unaltered in the long-run. Importantly, unemployment falls below its long-run level temporarily and reaches its trough after 2.5 years. The reason for this is twofold. First, wage inertia implies that wages take time to catch up to increased productivity. This raises the share of the match surplus received by firms temporarily who respond by expanding vacancy creation. Second, vacancy posting costs only depend on the current level of labor productivity whereas the value of a filled vacancy to a firm also depends on future productivity. Therefore, when productivity grows, the surplus is large relative to the costs of creating a vacancy which leads to an expansion in vacancy creation and low unemployment. As growth in labor productivity returns to its long-run trend, the difference between match surplus and vacancy posting costs declines, firms post fewer vacancies and unemployment increases.

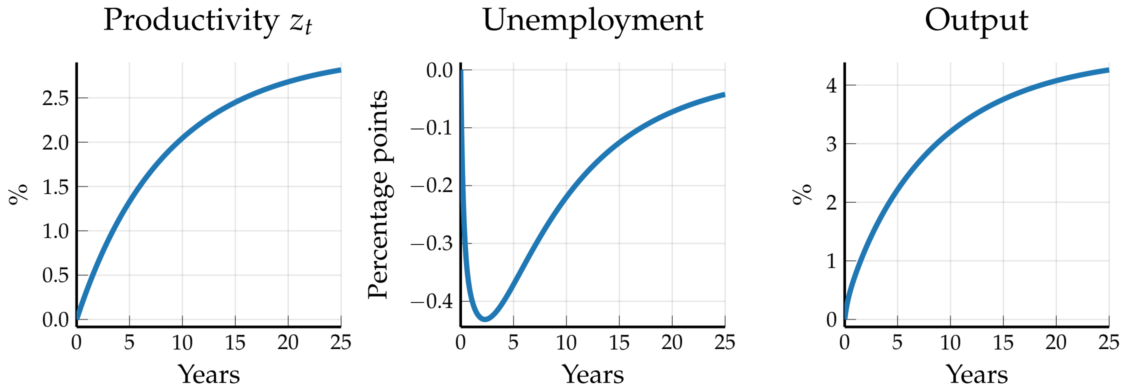


Figure 1.3: Long-run responses to the expansion of government investment

Notes: The figure shows the responses to a permanent expansion of public investment by 1% of initial GDP as deviations from the initial steady state.

So far, I have considered a permanent expansion in public investment. One might be concerned that the employment effects of a public investment program that is not permanent are substantially smaller. However, as Figure 1.D5 in the appendix shows, the short-run responses to an expansion of public investment by one percent of GDP over only 5 years is almost the same as for a permanent expansion in public investment.

5.1 Implementation delays

We now turn to implementation delays. The scenarios with implementation delays are of interest for two reasons. First, the existing literature has emphasized delays as an important characteristic of government investment, which sets it apart from consumptive government spending and which can impair its effectiveness as a means of short term stimulus (Leeper et al. 2010). Second, comparing how the economy responds to the investment program under different implementation delays allows us to better understand the mechanism through which it affects the economy in the short-run. In particular, it helps to disentangle the expectations effect from the consequences of the contemporaneous increase in productivity which is zero at first in the case of delay.

The dashed red lines in Figure 1.2 show the responses when it takes six months after the announcement of the investment program before it is implemented and starts to have an effect on productivity. The dotted green lines correspond to the case where the delay amounts to twelve months. Even when it takes six or twelve months for the investment program to have an effect on productivity, output, and unemployment respond already upon announcement of the investment program.

With an implementation delay of six months, unemployment is almost 0.35 percentage points lower twelve months after the announcement. This is more than three quarters of the decline without the delay. Similarly, output after one year is close to 0.6% higher than without the expansion in public investment. If the delay amounts to twelve months, the investment program still reduces unemployment after one year by about 0.22 percentage points, more than half the reduction without any delay. Output after twelve months is still close to 0.3% higher. Importantly, the increase in output and decline in unemployment take place before the investment program has had any effect on productivity (see the top left panel of Figure 1.2). The observed effect is entirely due to agents anticipating higher productivity in the future as a result of more government investment.

5.2 The anticipation effect

To quantify the contribution of the *anticipated* increase in future productivity to the reduction in unemployment, I consider the following hypothetical scenario. I assume that private agents do not learn about the permanent expansion in public investment in period zero. Instead, they expect productivity to stay constant at every point in time. In period zero, they expect productivity to stay at its steady state level forever. In period one, they are surprised that productivity has increased but expect it to stay at the new level such that in period two they are surprised again by the additional increase. In short, agents only learn about increases in productivity as they occur. The dashed purple line in Figure 1.4 shows the evolution of unemployment in this case. It still declines but more slowly than when the anticipation effect is present. After one year, unemployment has fallen by 0.13 percentage points, more than 65% less than in the baseline scenario. I interpret this difference as the contribution of the anticipation effect to the unemployment reduction.

An alternative way to quantify the anticipation effect is to consider the case where

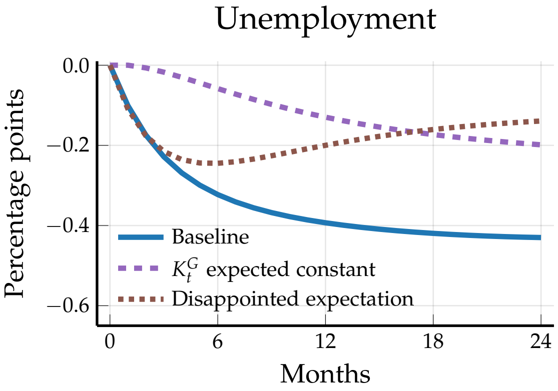


Figure 1.4: The anticipation effect on unemployment.

Notes: The dashed purple line shows the response of unemployment in a scenario where agents only find out about increases in productivity as they materialize and expect constant productivity at every point in time. The dotted brown line is the case where agents always expect the increase in productivity to start in the next period, although it never happens.

private agents expect the permanent expansion in public investment to begin at every point in time even though this is never the case. In other words, agents anticipate a permanent expansion of public investment in period zero and act accordingly. They are surprised in period one that productivity has not increased but believe that the increase is going to start in the next period when they are disappointed again. I could then interpret the change in unemployment under this scenario as the contribution of the anticipation effect to the overall reduction in unemployment. It is depicted by the dotted brown line in Figure 1.4. Initially, the response is identical to the one in the baseline scenario. The two then diverge since wages continue to rise as workers keep bargaining for higher wages in anticipation of increasing productivity even though this increase never materializes. After one year, unemployment has declined by 0.18 percentage points under this scenario. This amounts to 45% of the reduction in the baseline scenario. Accordingly, I would attribute 45% of the unemployment reduction to the anticipation effect.

For both definitions, the anticipation effect accounts for a large part of the reduction in unemployment in response to the expansion in public investment.

5.3 Labor supply response

Higher future productivity due to the announcement of the public investment program affects not only firms' labor demand but also the behavior of workers, the supply side of the labor market. Two changes in workers' behavior are important. First, workers demand a higher wage. Since higher future productivity increases the expected total surplus from the match, the Nash-bargained wage increases already today which raises wages. The wage increase depends on workers' bargaining weight and the degree of wage inertia. Figure 1.5 shows that the news about higher future productivity raise the

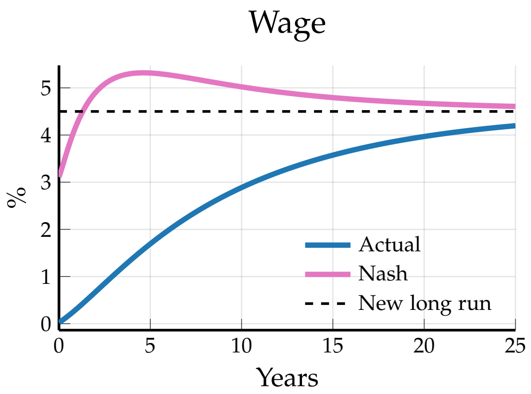


Figure 1.5: Responses of actual and Nash bargaining wage.
Notes: The figure shows the responses to a permanent expansion of public investment by 1% of initial GDP as percentage deviations from the initial steady state.

Nash-bargained wage substantially, by 3% on impact. Due to wage inertia, the increase in Nash wages only gradually translates into actual wage gains and the actual wage increases almost linearly during the first years after the start of the investment program.

Second, workers also respond to the anticipated increase in productivity by adjusting their search effort. To assess the importance of workers' search effort, I decompose the change in the job finding probability in every period according to

$$\pi_0^{e|u} - \bar{\pi}^{e|u} = \underbrace{\frac{\pi_0^{e|u}}{\ell_0(u)}\bar{\ell}(u) - \frac{\bar{\pi}^{e|u}}{\bar{\ell}(u)}\bar{\ell}(u)}_{\text{vacancy posting}} + \underbrace{\frac{\pi_0^{e|u}}{\ell_0(u)}\ell_0(u) - \frac{\pi_0^{e|u}}{\ell_0(u)}\bar{\ell}(u)}_{\text{search effort}}, \tag{1.33}$$

where a bar denotes the variable in the initial steady state. The left panel of Figure 1.6 shows this decomposition graphically. The blue line is the total change in the job finding probability, the left-hand side of (1.33). The dashed green line is the part due to changes in search effort, the terms labeled "search effort" in (1.33), and the gray line is the part due to changes in labor demand, the terms labeled "vacancy posting" in (1.33). The increase in the job finding probability is almost entirely due to changes in firms' labor demand. Search effort also contributes to the increase, but its effect is negligible. In the first period, the job finding probability increases by 1.4819 percentage points. Only 0.0005 percentage points are due to the expansion in search effort.

Two forces drive the response of effort: the expected gain in lifetime utility from finding a job and the marginal effect of higher effort on the job finding probability (see equation (1.12)). The center panel in Figure 1.6 shows that the expected gain in lifetime utility from finding a job declines in response to the investment program. The reason is that job-finding rates increase such that unemployed workers can expect to stay unemployed for a shorter period of time. This effect dominates the increase in wages which would lead to an increase in the difference between expected lifetime utility of

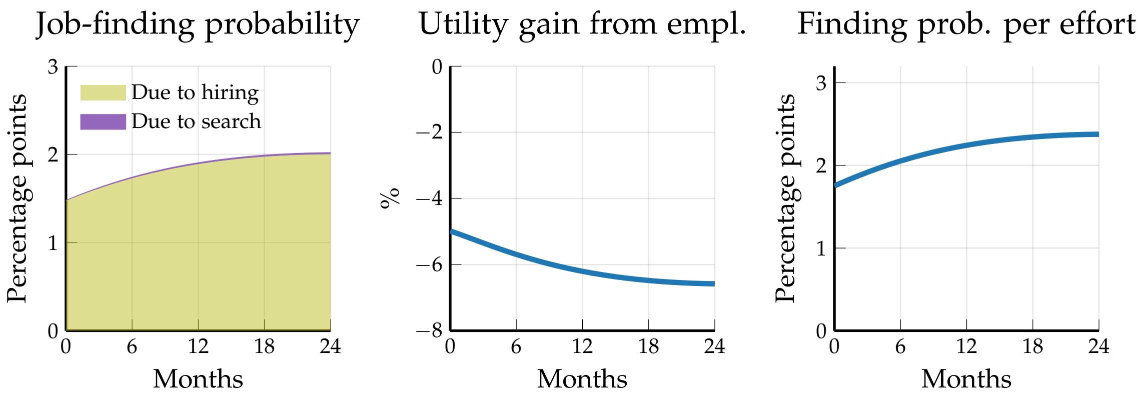


Figure 1.6: The response of the job-finding probability.

Notes: The figure shows the responses to a permanent expansion of public investment by 1% of initial GDP as deviations from the initial steady state.

employed and unemployed workers. The drop in the expected gain in lifetime utility from finding a job would lead workers to lower their search effort. However, for the baseline scenario, this effect is outweighed by the increase in the job-finding probability per unit of effort, which equals the marginal increase in the job finding probability due to the linearity of the job finding probability in effort. The job-finding probability per unit of effort is depicted in the right panel of Figure 1.6. In other words, it is the immediate increase in labor demand due to the anticipation effect that prevents workers from reducing search effort. The anticipation effect on short-run labor demand has two effects on employment. It increases the job finding probability directly and thereby raises employment. But it also has an indirect effect on employment as it causes workers to expand search effort.

5.4 Financing with distortionary labor taxes

So far, I have assumed that the government finances the investment program with non-distortionary lump-sum taxes on firm owners. An alternative policy would be to raise the proportional labor tax to finance public investment. I assume that the government cannot shift the tax burden over time by issuing debt but that it has to raise labor taxes at the same time that expenditures increase. Figure 1.7 shows the responses of key variables in this. As can be seen from the top left panel, unemployment falls less in response to the program in this case, but it still declines substantially. After one year, it is 0.25 percentage points lower than without the program.

There are two forces that dampen the reduction in unemployment compared to the baseline scenario. First, the increase in the labor tax rate leads to a faster increase in wages as Nash bargaining implies that workers and firms share the tax burden depending on their bargaining weights. Since wages rise faster, firms do not expand vacancy creation as much as in the baseline. This can be seen from the bottom left panel in Figure 1.7 which shows that the job finding probability per unit of search effort increases less

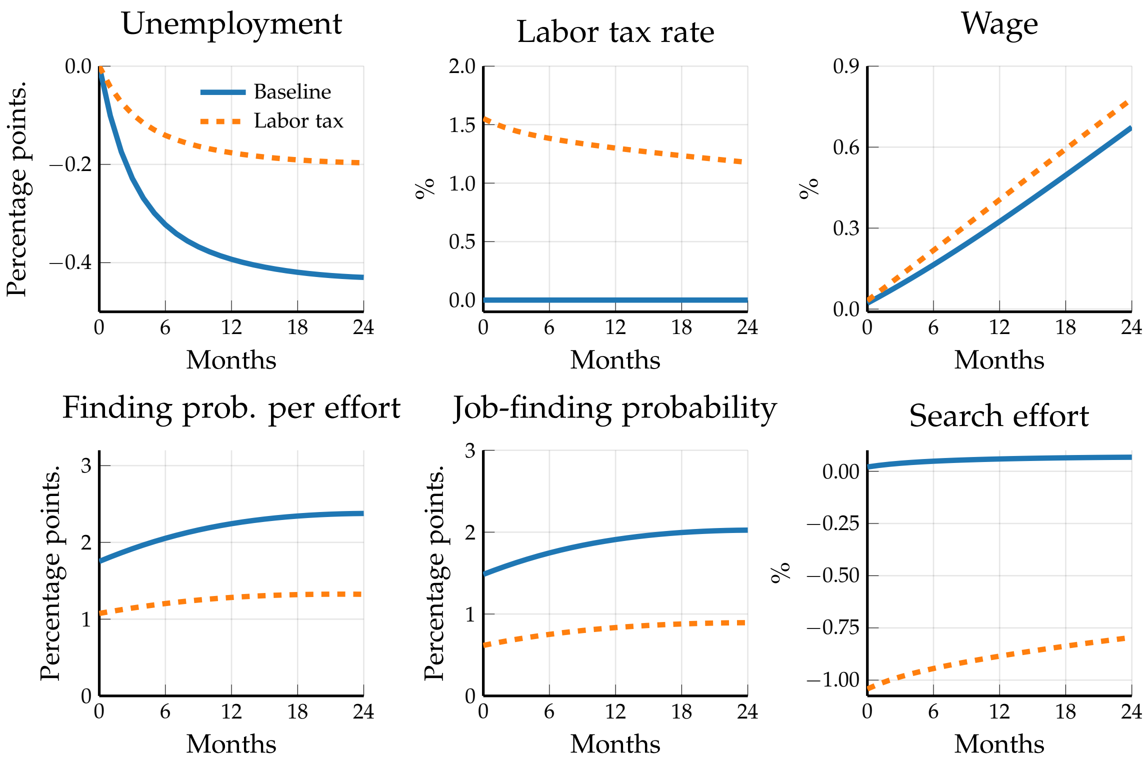


Figure 1.7: Responses to the investment program financed with proportional labor taxes. *Notes:* The figure shows the responses to a permanent expansion of public investment by 1% of initial GDP as deviations from the initial steady state.

if the program is financed with labor taxes. The second force through which labor taxes reduce the employment effect is workers' search effort. It is lower than in the case of lump-sum taxes and actually declines relative to the steady state. There are two reasons for this. First, firms expand vacancy creation less such that the marginal effect of effort on the job finding probability is lower. Second, the increase in the labor tax reduces the income difference between unemployed and employed workers such that unemployed workers exert less effort.

5.5 Business cycle dependence

I established in Proposition 2, that the size of the employment effect depends on the initial level of unemployment. How large are the differences between boom and recession?

To address this question, I follow the same approach as in Section 3 and define a recession as an equilibrium with high unemployment and weak labor demand. More specifically, unemployment is 3 percentage points higher than in the steady state and the wage is 2% higher. I define a boom symmetrically, as an equilibrium in which initial unemployment is 3 percentage points lower and the wage 2% higher. The unemployment rate in the recession is thus 9.5 percent, similar to the levels in 2009 to 2010 during the Great Recession. The unemployment rate in the boom is 3.5 percent, close to the rates observed in 2019. I further assume that unemployment benefits are constant at the steady state level. Moreover, the capital to labor ratio is also at the steady state level initially, i.e., the private capital stock is smaller in a recession and higher in a boom.

I study the perfect foresight equilibrium under these differential initial conditions and compare the case with an expansion in public investment to the one without. Figure 1.8 shows the evolution of unemployment, labor market tightness and wages for the two cases. In a recession, labor market tightness is about twice as large as in a boom. A factor of two roughly corresponds to the difference between the trough in tightness at around 0.35 in August 2003 and the peak at 0.73 in March 2007. Comparing the Great Recession to the following expansion, the differences in tightness are even larger. Labor market tightness in 2019 was about 7 times higher than in 2010, 1.2 compared to 0.17.

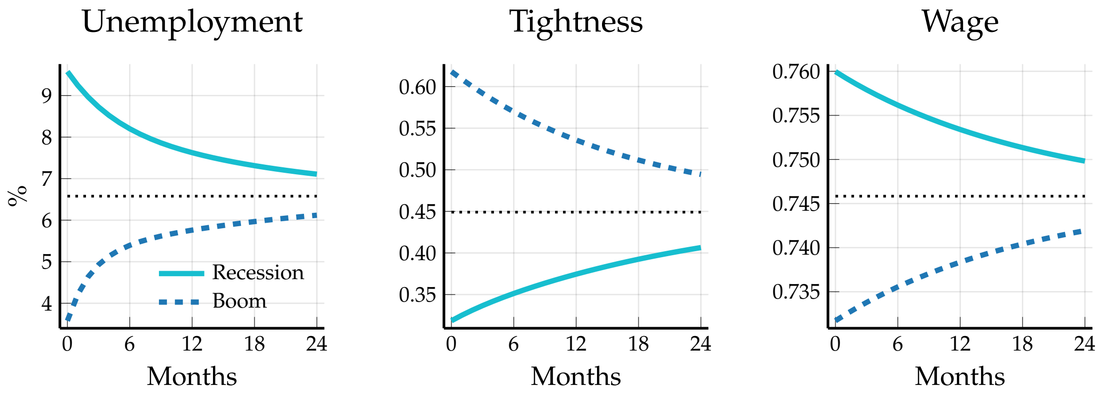


Figure 1.8: Unemployment, labor market tightness and wages in recession and boom.
Notes: The black dotted line denotes the steady state. Unemployment in percent, wages in units of the consumption good.

Figure 1.9 shows how unemployment and output respond to the expansion in public investment for the case where the economy is in a recession initially and for the case where it is in a boom. Shown are the deviations from the paths that would be observed without the investment program, i.e., those shown in Figure 1.8. When the economy is in a recession initially, the short-run response of both unemployment and output is much larger than when the economy is in a boom. One year after the expansion in public investment, unemployment has fallen by 0.57 percentage points in the case of a recession whereas it has only fallen by 0.4 percentage points in case of a boom. This is a difference of more than 40%.

I also compare recessions and booms that are the result of shocks to productivity. I consider a recession due to a negative shock to productivity of one standard deviation,

$$\log A_0 = -0.0056$$

and accordingly, for a boom

$$\log A_0 = +0.0056,$$

after which productivity A_t evolves according to (1.32). In this case, the employment

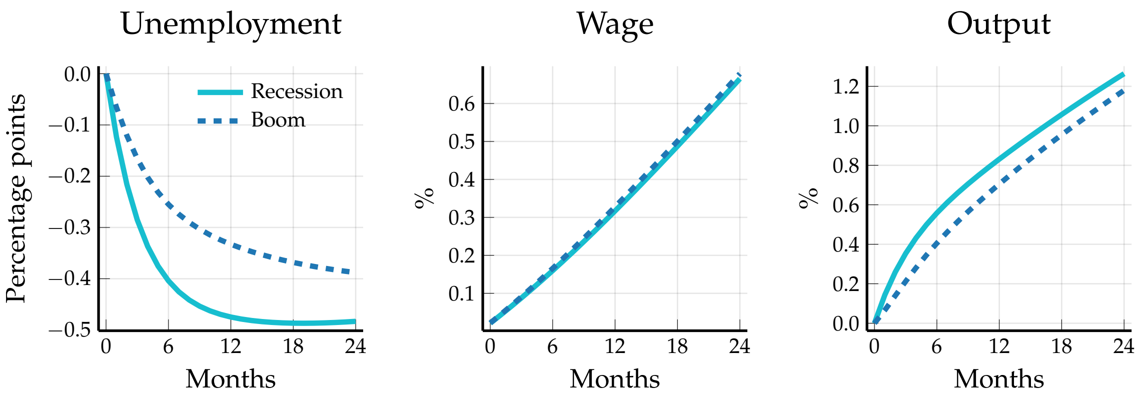


Figure 1.9: Response of unemployment and output.

Notes: Shown are the deviations from the respective paths that would be observed without the expansion in public investment (see Figure 1.8).

effect after one year is about 25% larger when the expansion of public investment is initiated in a recession compared to a boom. I show the corresponding impulse response functions in Appendix D.1.

6 Conclusion

Recently, policymakers in several countries have proposed plans to expand public infrastructure investment. The hope was that public investment would not only foster long-run economic growth but also provide some stimulus to support the recovery from the Covid-19 recession. To address the question whether public investment is suited to provide this stimulus, the existing literature has relied on variants of the neoclassical growth model with frictionless labor markets. In this paper, I revisited this question in another widely used macroeconomic model, the Diamond-Mortensen-Pissarides search and matching model. My theoretical analysis highlighted the role of firms' expectations about future productivity for their hiring decision and the short-run employment effect of public investment. When firms anticipate higher productivity in the future, they expand hiring already in the short run. This mechanism is absent in models without labor market frictions. For a realistic calibration of the model, the anticipation effect is large. It accounts for 65% of the reduction in unemployment by 0.4 percentage points within one year after a permanent expansion of public investment by 1% of GDP. The size of the employment effect depends on the state of the business cycle. It is about 40% larger in a recession than in a boom.

These findings are relevant for policymakers. They suggest that a permanent change in fiscal policy towards more public investment can provide a substantial short-run stimulus by raising labor demand. These short-run employment effects are especially large in a recession when labor demand is weak. Thus, a recession might be a good time to initiate a change in fiscal policy towards more public investment. Because much of the short-run employment effects of the change in fiscal policy are due to the anticipation effect, the announcement of the policy change already leads to significant employment effects. The exact timing of the implementation is of lesser importance, and credibly announcing the change during a recession is enough to stabilize employment.

In this paper, I analyzed and quantified the employment effect of public investment in a standard search and matching model with private and public capital. I focused on the anticipation effect on labor demand and abstracted from some forces, which could further amplify the employment effect of public investment. First, in addition to the anticipation effect, there is likely a direct effect on labor demand as the public sector and its private contractors, who build the additional infrastructure, hire more workers. Second, as public investment raises the job-finding probability in the short run, workers will fear unemployment less, reduce precautionary savings, and consume more. This could stimulate the economy further if output is partially demand determined (see for example Den Haan et al. 2017; Ravn and Sterk 2020). Third, separations are exogenous in my model but partly depend on firms' choices in reality. I expect that accounting for endogenous separations will lead to larger employment effects as firms will lay off fewer workers if they anticipate productivity to rise in the future. In addition, if firms can endogenously lower the separation rate, labor hoarding is facilitated, further amplifying the effect of public investment on hiring.

It would be interesting to investigate heterogeneity in employment effects across industries and occupations. In light of the results presented in this paper, I would expect larger increases in employment in industries and occupations in which labor productivity benefits most from infrastructure investment. For example, effects may be especially large in the transportation and logistics industry, which benefit strongly from better roads and ports. Employment in repair and maintenance occupations might also respond strongly as these occupations benefit from improvements in telecommunication infrastructure. The employment effects should also be more prominent in industries and occupations in which expected job tenure is longer, which makes it easier for firms to hoard labor.

The theoretical relationship between public investment and employment studied in this paper crucially depends on the effect of public investment on firms' expectations about future productivity. Firms only expand hiring in the short run if they believe that productivity will rise. This requires a credible commitment by the government to raise public investment persistently. A short-lived expansion in public investment that only brings public investment forward in time but does not raise productivity persistently will have much smaller employment effects. Some past expansions in public investment may have satisfied this requirement, whereas others may not. It is an interesting empirical question whether this difference can account for disparate estimates of the short-run output and employment effects of public investment.

Appendix A Definitions and Proofs

A.1 Equilibrium Definition

An equilibrium of this economy is defined as follows.

Definition 2 (Equilibrium). *An equilibrium is a collection of individual sequences of workers' effort and consumption* $\{\ell_t(s^t), c_t(s^t))\}_{t=0}^{\infty}$*, of labor market tightness, capital rental rates and wages,* $\{\theta_t, r_t^k, w_t\}_{t=0}^{\infty}$*, aggregate employment, aggregate capital, and capital per match,* $\{N_t, K_t, k_t\}_{t=0}^{\infty}$*, and of policies* $\{T_t, \tau_t, K_t^G, I_t^G\}_{t=0}^{\infty}$*, such that*

1. *the sequences of effort and consumption* $\{(\ell_t(s^t), c_t(s^t)\}_{t=0}^{\infty}$ *solve the worker problem* (1.10)*,*
2. *firms choose capital optimally according to* (1.5)*,*
3. *the sequence of labor market tightness* $\{\theta_t\}_{t=0}^{\infty}$ *ensures that the value of an open vacancy is zero,* $V_t(\theta_t) = 0$*,*
4. *wages are determined according to* (1.19) *together with* (1.21) *or* (1.20)*,*
5. *firm owners choose capital optimally according to* (1.17)*,*
6. *the capital market clears* $K_t = k_t N_t$*,*
7. *employment follows the law of motion* (1.13)*,*
8. *the government budget constraint* (1.23) *holds, public capital follows the law of motion* (1.22) *and determines productivity according to* (1.2)*.*

A.2 Proof of Proposition 1

The proof proceeds as follows. First, I derive the effect of the expansion in public investment on the sequence of job-finding probabilities. For part i), I show that the job-finding probability strictly increases. The positive employment effect then follows from the law of motion for employment, (1.13). For part ii), I show that the change in the job-finding probability goes to zero in the long run, as $t \to \infty$ if wages are not completely sticky. The law of motion for employment then implies that employment is unchanged in the long run.

The job-finding probability is

$$\pi_t^{e|u} = \zeta^{\frac{1}{\eta}} q_t^{v\frac{\eta-1}{\eta}}.$$

Without adjustment costs, capital in every match is

$$k_t = \left(\frac{\alpha\beta}{1-\beta(1-\delta)} \right)^{\frac{1}{1-\alpha}} z_t^{\frac{1}{1-\alpha}}$$

such that the job creation equation yields

$$q_t^v = \frac{\kappa a^\alpha z_t^{\frac{1}{1-\alpha}}}{\sum_{s=1}^{\infty} \beta^s (1-\rho)^{s-1} \left\{ (1-\alpha) a^\alpha z_{t+s}^{\frac{1}{1-\alpha}} - w_{t+s} \right\}}$$

with $a \equiv \left(\frac{\alpha\beta}{1-\beta(1-\delta)} \right)^{\frac{1}{1-\alpha}}$. Hence, the job-finding probability is

$$\begin{aligned} \pi_t^{e|u} =& \zeta^{\frac{1}{\eta}} \beta^{\frac{1-\eta}{\eta}} \left(z_t^{\frac{1}{1-\alpha}} \kappa a^\alpha \right)^{\frac{\eta-1}{\eta}} \\ & \times \left[\sum_{s=t}^{\infty} (\beta(1-\rho))^{s-k} \left[(1-\alpha) a^\alpha z_{s+1}^{\frac{1}{1-\alpha}} - w_{s+1} \right] \right]^{\frac{1-\eta}{\eta}}. \end{aligned}$$

The job-finding probability depends on the sequence of private productivity z_s and on the wage sequence w_s. For this reason, we determine next, how private productivity z_s and the wage w_s respond to the marginal increase in investment.

Productivity is

$$z_s = A \left(K_s^G \right)^\vartheta$$

and so

$$\frac{\mathrm{d}z_s}{\mathrm{d}x} = A\vartheta {K_s^G}^{\vartheta-1} \frac{\mathrm{d}K_s^G}{\mathrm{d}x} = z_n \frac{\vartheta}{K_s^G} \frac{\mathrm{d}K_s^G}{\mathrm{d}x}.$$

Furthermore,

$$K_s^G = (1-\delta_G)^s K_0^G + \sum_{j=0}^{s-1} (1-\delta_G)^{s-1-j} I_j^G + \sum_{j=T}^{s-1} (1-\delta_G)^{s-1-j} x$$

such that

$$\frac{\mathrm{d}K_s^G}{\mathrm{d}x} = \sum_{j=T}^{s-1} (1-\delta_G)^{s-1-j}$$

and

$$\frac{\mathrm{d}z_s}{\mathrm{d}x} = z_s \frac{\vartheta}{K_s^G} \sum_{j=T}^{s-1} (1-\delta_G)^{s-1-j}.$$

By assumption $I^G = \delta_G K_s^G$ for all s, such that z_s is constant and

$$\frac{\mathrm{d}z_s}{\mathrm{d}x} = \begin{cases} \frac{\vartheta z_s}{I^G}(1-(1-\delta_G)^{s-T}), & \text{if } s > T \\ 0 \quad \text{if } s \leq T. \end{cases}$$

The wage is

$$w_s = \gamma^s w_0 + \sum_{n=1}^{t} (1-\gamma)\omega a^\alpha z_n^{\frac{1}{1-\alpha}} \gamma^{t-n}$$

such that

$$\frac{\mathrm{d}w_s}{\mathrm{d}x} = \sum_{n=1}^{s} \gamma^{s-n}(1-\gamma)\omega a^\alpha \frac{1}{1-\alpha} z_n^{\frac{\alpha}{1-\alpha}} \frac{\mathrm{d}z_n}{\mathrm{d}x}.$$

I distinguish two cases, $t \leq T$ and $t > T$.

Case 1: $t \leq T$ The semi-elasticity of the job-finding probability in period $t \leq T$ with respect to public investment in the periods after T is

$$\begin{aligned}
\frac{\mathrm{d}\pi_t^{e|u}}{\mathrm{d}x}|_{x=0} =& \pi_t^{e|u} \left[\frac{(1-\alpha-\omega)a^\alpha z^{\frac{1}{1-\alpha}}}{1-\beta(1-\rho)} - \frac{\gamma^{t+1} w_0}{1-\beta\gamma(1-\rho)} + \frac{\omega a^\alpha z^{\frac{1}{1-\alpha}} \gamma^{t+1}}{1-\gamma\beta(1-\rho)} \right]^{-1} \frac{1-\eta}{\eta} \frac{1}{1-\alpha} \\
& z^{\frac{\alpha}{1-\alpha}} \left[\sum_{s=T}^{\infty} (\beta(1-\rho))^{s-t} \left[(1-\alpha)a^\alpha \frac{\partial z_{s+1}}{\partial x} - (1-\gamma)\omega a^\alpha \sum_{n=T+1}^{s+1} \gamma^{s+1-n} \frac{\partial z_n}{\partial x} \right] \right] \\
=& \pi_t^{e|u} \left[\frac{(1-\alpha-\omega)a^\alpha}{1-\beta(1-\rho)} - \frac{\gamma^{t+1} w_0 z^{\frac{1}{\alpha-1}}}{1-\beta\gamma(1-\rho)} + \frac{\omega a^\alpha \gamma^{t+1}}{1-\gamma\beta(1-\rho)} \right]^{-1} \frac{1-\eta}{\eta} \frac{1}{1-\alpha} \\
& \frac{\vartheta}{\delta_G K_G} (\beta(1-\rho))^{T-t} \Bigg[(1-\alpha)a^\alpha \left(\frac{1}{1-\beta(1-\rho)} - \frac{1-\delta_G}{1-\beta(1-\delta_G)(1-\rho)} \right) \\
& - (1-\gamma)\omega a^\alpha \sum_{s=T}^{\infty} (\beta(1-\rho))^{s-T} \sum_{n=T+1}^{s+1} \gamma^{s+1-n} \left(1-(1-\delta_G)^{n-T}\right) \Bigg] \\
=& \pi_t^{e|u} \left[\frac{(1-\alpha-\omega)a^\alpha}{1-\beta(1-\rho)} - \frac{\gamma^{t+1} w_0 z^{\frac{1}{\alpha-1}}}{1-\beta\gamma(1-\rho)} + \frac{\omega a^\alpha \gamma^{t+1}}{1-\gamma\beta(1-\rho)} \right]^{-1} \frac{1-\eta}{\eta} \frac{1}{1-\alpha} \\
& \vartheta (\beta(1-\rho))^{T-t} \Bigg[(1-\alpha)a^\alpha \frac{\delta_G}{(1-\beta(1-\rho))(1-\beta(1-\delta_G)(1-\rho))} \\
& - (1-\gamma)\omega a^\alpha \sum_{s=T}^{\infty} (\beta(1-\rho))^{s-T} \sum_{n=T+1}^{s+1} \gamma^{s+1-n} \left(1-(1-\delta_G)^{n-T}\right) \Bigg] \frac{1}{I^G}.
\end{aligned}$$

Focusing on the last summand, it holds that

$$\sum_{n=T+1}^{s+1} \gamma^{s+1-n} \left(1-(1-\delta_G)^{n-T}\right) = \left(\frac{\gamma^{s-T+1}-1}{\gamma-1} - (1-\delta_G) \frac{\gamma^{s-T+1}-(1-\delta_G)^{s-T+1}}{\gamma-1+\delta} \right)$$

such that

$$\begin{aligned}
&\sum_{s=T}^{\infty}(\beta(1-\rho))^{s-t}\sum_{n=T+1}^{s+1}\gamma^{s+1-n}\left(1-(1-\delta_G)^{n-t}\right)\\
&=\sum_{s=T}^{\infty}(\beta(1-\rho))^{s-t}\Big(\frac{\gamma^{s-T+1}-1}{\gamma-1}-(1-\delta_G)\frac{\gamma^{s-T+1}-(1-\delta_G)^{s-T+1}}{\gamma-1+\delta}\Big)\\
&=\left(\frac{1}{1-\beta\gamma(1-\rho)}\left(\frac{\gamma}{\gamma-1}-\frac{(1-\delta_G)\gamma}{\gamma-1+\delta_G}\right)-\frac{1}{\gamma-1}\frac{1}{1-\beta(1-\rho)}\right.\\
&\quad\left.+(1-\delta_G)^2\frac{1}{\gamma-1+\delta_G}\frac{1}{1-\beta(1-\rho)(1-\delta_G)}\right)\\
&=\frac{1}{(1-\gamma)(1-\gamma-\delta_G)}\left(\frac{\delta_G\gamma^2}{1-\beta\gamma(1-\rho)}+\frac{1-\gamma-\delta_G}{1-\beta(1-\rho)}-\frac{(1-\gamma)(1-\delta_G)^2}{1-\beta(1-\rho)(1-\delta_G)}\right)
\end{aligned}$$

and so

$$\begin{aligned}
\frac{\mathrm{d}\pi_t^{e|u}}{\mathrm{d}x}\Big|_{x=1}=&\pi_t^{e|u}\left[\frac{(1-\alpha-\omega)a^\alpha}{1-\beta(1-\rho)}-\frac{\gamma^{t+1}w_0z^{\frac{1}{\alpha-1}}}{1-\beta\gamma(1-\rho)}+\frac{\omega a^\alpha\gamma^{t+1}}{1-\gamma\beta(1-\rho)}\right]^{-1}\frac{1-\eta}{\eta}\frac{1}{1-\alpha}\\
&\vartheta(\beta(1-\rho))^{T-t}\left[a^\alpha\frac{\delta_G(1-\alpha-\omega)}{(1-\beta(1-\rho))(1-\beta(1-\delta_G)(1-\rho))}\right.\\
&\left.+\frac{\gamma\omega a^\alpha\delta_G}{(1-\beta\gamma(1-\rho))(1-\beta(1-\rho)(1-\delta_G))}\right]\frac{1}{I^G}
\end{aligned} \tag{1.34}$$

Case 2: $t > T$

$$\begin{aligned}
\frac{\mathrm{d}\pi_t^{e|u}}{\mathrm{d}x}\Big|_{x=0} =& \pi_t^{e|u} \left[z^{\frac{1}{1-\alpha}} \frac{(1-\alpha-\omega)a^{\alpha}}{1-\beta(1-\rho)} - \frac{\gamma^{t+1} w_0}{1-\beta\gamma(1-\rho)} + \frac{\omega a^{\alpha} z^{\frac{1}{1-\alpha}} \gamma^{t+1}}{1-\gamma\beta(1-\rho)} \right]^{-1} \\
& \frac{1-\eta}{\eta} \frac{1}{1-\alpha} z^{\frac{\alpha}{1-\alpha}} \left[\sum_{s=t}^{\infty} (\beta(1-\rho))^{s-t} \left[(1-\alpha) a^{\alpha} \frac{\partial z_{s+1}}{\partial x} \right.\right. \\
& \left.\left. - (1-\gamma)\omega a^{\alpha} \sum_{n=T+1}^{s+1} \gamma^{s+1-n} \frac{\partial z_n}{\partial x} \right]\right] \\
& + \pi_t^{e|u} \vartheta \frac{\eta-1}{\eta} \frac{1}{1-\alpha} \left(1 - (1-\delta_G)^{t-T} \right) \\
=& \frac{(1-\eta)\pi_t^{e|u}}{(1-\alpha)\eta} \frac{\vartheta}{I^G} \left\{ \left[\frac{(1-\alpha-\omega)a^{\alpha}}{1-\beta(1-\rho)} - \frac{\gamma^{t+1} w_0 z^{\frac{1}{\alpha-1}}}{1-\beta\gamma(1-\rho)} + \frac{\omega a^{\alpha} \gamma^{t+1}}{1-\gamma\beta(1-\rho)} \right]^{-1} \right. \\
& \left[(1-\alpha-\omega) a^{\alpha} \left(\frac{1}{1-\beta(1-\rho)} - (1-\delta_G)^{t-T+1} \frac{1}{1-\beta(1-\rho)(1-\delta_G)} \right) \right. \\
& \left. + \frac{\gamma\omega\delta_G a^{\alpha}}{1-\gamma-\delta_G} \left(\frac{(1-\delta_G)^{t-T+1}}{1-\beta(1-\delta_G)(1-\rho)} - \frac{\gamma^{t-T+1}}{1-\beta\gamma(1-\rho)} \right) \right] \\
& \left. - \left(1 - (1-\delta_G)^{t-T}\right) \right\}
\end{aligned} \tag{1.35}$$

With $w_0 = \omega a^{\alpha} z^{\frac{1}{1-\alpha}}$, I get

$$\begin{aligned}
\frac{\mathrm{d}\pi_t^{e|u}}{\mathrm{d}x}\Big|_{x=0} =& \frac{(1-\eta)\pi_t^{e|u}}{(1-\alpha)\eta} \frac{\vartheta}{I^G} \left\{ \left(1 - (1-\delta_G)^{t-T+1} \frac{1-\beta(1-\rho)}{1-\beta(1-\rho)(1-\delta_G)} \right) \right. \\
& - \left(1 - (1-\delta_G)^{t-T}\right) \\
& \left. + \frac{(1-\beta(1-\rho))\gamma\omega\delta_G}{(1-\gamma-\delta_G)(1-\alpha-\omega)} \left(\frac{(1-\delta_G)^{t-T+1}}{1-\beta(1-\delta_G)(1-\rho)} - \frac{\gamma^{t-T+1}}{1-\beta\gamma(1-\rho)} \right) \right\} \\
=& \frac{(1-\eta)\pi_t^{e|u}}{(1-\alpha)\eta} \frac{\vartheta}{I^G} \left\{ \frac{(1-\delta_G)^{t-T+1}\delta_G}{1-\beta(1-\rho)(1-\delta_G)} \right. \\
& \left. + \frac{(1-\beta(1-\rho))\gamma\omega\delta_G}{(1-\gamma-\delta_G)(1-\alpha-\omega)} \left(\frac{(1-\delta_G)^{t-T+1}}{1-\beta(1-\delta_G)(1-\rho)} - \frac{\gamma^{t-T+1}}{1-\beta\gamma(1-\rho)} \right) \right\}
\end{aligned}$$

For the proof of part i), note that in both cases $\frac{\partial \pi_t^{e|u}}{\partial x}|_{x=0} > 0$ (assuming that the job-finding probability in the initial equilibrium is strictly positive). The result follows directly for the case $t \leq T$ since $\pi_t^{e|u} > 0$ only if

$$\left[\frac{(1-\alpha-\omega)a^{\alpha}}{1-\beta(1-\rho)} - \frac{\gamma^{t+1}w_0 z^{\frac{1}{\alpha-1}}}{1-\beta\gamma(1-\rho)} + \frac{\omega a^{\alpha}\gamma^{t+1}}{1-\gamma\beta(1-\rho)}\right]^{-1} > 0.$$

For the case $t > T$, the crucial step is to note that the wage stickiness term is always positive,

$$\frac{\gamma\omega\delta_G a^{\alpha}}{1-\gamma-\delta_G}\left(\frac{(1-\delta_G)^{t-T+1}}{1-\beta(1-\delta_G)(1-\rho)} - \frac{\gamma^{t-T+1}}{1-\beta\gamma(1-\rho)}\right) > 0.$$

This is the case since

$$\left(\frac{(1-\delta_G)^{t-T+1}}{1-\beta(1-\delta_G)(1-\rho)} - \frac{\gamma^{t-T+1}}{1-\beta\gamma(1-\rho)}\right) > 1-\delta_G-\gamma$$

if and only if $\gamma < 1-\delta_G$. In this case, $1-\delta_G-\gamma > 0$ such that also

$$\left(\frac{(1-\delta_G)^{t-T+1}}{1-\beta(1-\delta_G)(1-\rho)} - \frac{\gamma^{t-T+1}}{1-\beta\gamma(1-\rho)}\right) > 0$$

and thus

$$\frac{\gamma\omega\delta_G a^{\alpha}}{1-\gamma-\delta_G}\left(\frac{(1-\delta_G)^{t-T+1}}{1-\beta(1-\delta_G)(1-\rho)} - \frac{\gamma^{t-T+1}}{1-\beta\gamma(1-\rho)}\right) > 0.$$

If in contrast $\gamma > 1-\delta_G$, then $1-\delta_G-\gamma < 0$ and

$$\left(\frac{(1-\delta_G)^{t-T+1}}{1-\beta(1-\delta_G)(1-\rho)} - \frac{\gamma^{t-T+1}}{1-\beta\gamma(1-\rho)}\right) < 0$$

such that also in this case

$$\frac{\gamma\omega\delta_G a^{\alpha}}{1-\gamma-\delta_G}\left(\frac{(1-\delta_G)^{t-T+1}}{1-\beta(1-\delta_G)(1-\rho)} - \frac{\gamma^{t-T+1}}{1-\beta\gamma(1-\rho)}\right) > 0.$$

I have shown that $\frac{\mathrm{d}\pi_t^{e|u}}{\mathrm{d}x}|_{x=0} > 0$ for all t if the initial wage is $w_0 = \omega a^{\alpha} z^{\frac{1}{1-\alpha}}$. By induction, it then follows from the law of motion for employment, that

$$\frac{\mathrm{d}N_t}{\mathrm{d}x} > 0$$

which proves part (i) of proposition 1 for the case where the initial wage is $w_0 = \omega a^{\alpha} z^{\frac{1}{1-\alpha}}$.

It can be seen from (1.34) and (1.35) that for given $\pi_t^{e|u}$, $\frac{\mathrm{d}\pi_t^{e|u}}{\mathrm{d}x}|_{x=0}$ is weakly increasing in w_0. Hence, as long as $\pi_t^{e|u} > 0$, the statement in (i) also holds if $w_0 > \omega a^{\alpha} z^{\frac{1}{1-\alpha}}$.

To prove part (ii), observe that for $t \to \infty$ we have $t > T$ and since $\lim_{t\to\infty} \frac{\mathrm{d}\pi_t^{e|u}}{\mathrm{d}x}|_{x=0} =$

0, it follows from the law of motion for employment that

$$\lim_{t\to\infty}\frac{\mathrm{d}N_t}{\mathrm{d}x} = 0.$$

A.3 Proof of Proposition 2

For the case $k \leq T$, we get from above with $w_0 = \omega a^\alpha z^{\frac{1}{1-\alpha}}$,

$$\begin{aligned}
\frac{\mathrm{d}\pi_k^{e|u}}{\mathrm{d}x}|_{x=0} =& \frac{(1-\eta)\pi_k^{e|u}}{(1-\alpha)\eta}\frac{\vartheta}{I^G}(\beta(1-\rho))^{T-k}\left[\frac{(1-\alpha-\omega)a^\alpha}{1-\beta(1-\rho)}\right]^{-1} \\
& \Bigg[(1-\alpha)a^\alpha\left(\frac{1}{1-\beta(1-\rho)} - \frac{1-\delta_G}{1-\beta(1-\delta_G)(1-\rho))}\right) \\
& - \frac{\omega a^\alpha}{(1-\gamma-\delta_G)}\left(\frac{\delta_G\gamma^2}{1-\beta\gamma(1-\rho)} + \frac{1-\gamma-\delta_G}{1-\beta(1-\rho)} - \frac{(1-\gamma)(1-\delta_G)^2}{1-\beta(1-\rho)(1-\delta_G)}\right)\Bigg] \\
& + \frac{\gamma\omega a^\alpha\delta_G}{(1-\beta\gamma(1-\rho))(1-\beta(1-\rho)(1-\delta_G))}\Bigg] \\
=& \frac{(1-\eta)\pi_k^{e|u}}{(1-\alpha)\eta}\frac{\delta_G\vartheta(\beta(1-\rho))^{T-k}}{1-\beta(1-\delta_G)(1-\rho)}\left[1+\frac{\gamma\omega(1-\beta(1-\rho))}{(1-\beta\gamma(1-\rho))(1-\alpha-\omega)}\right]\frac{1}{I^G}.
\end{aligned}$$

If the economy is at the steady state initially, then the employment multiplier is

$$\begin{aligned}
M_t^{Inv}(T,\mathcal{X}_0,\mathcal{I}^G) =& \sum_{k=0}^{t-1}(1-\rho-\pi^{e|u})^{t-k-1}(1-N)\frac{\partial\pi_k^{e|u}}{\partial x} \\
=& \frac{(\beta(1-\rho))^{T+1-t}(1-N)\vartheta}{1-\beta(1-\delta_G)(1-\rho)}\frac{\pi^{e|u}}{K^G}\frac{1}{1-\alpha}\frac{1-\eta}{\eta} \\
& \times\frac{1-((1-\rho-\pi^{e|u})\beta(1-\rho))^t}{1-((1-\rho-\pi^{e|u})\beta(1-\rho))}\left[1+\frac{\gamma\omega(1-\beta(1-\rho))}{(1-\beta\gamma(1-\rho))(1-\alpha-\omega)}\right].
\end{aligned}$$

A.4 Proof of Proposition 3

Part i) follows by induction, from the fact that $\frac{\mathrm{d}\pi_k^{e|u}}{\mathrm{d}x}|_{x=0}$ is independent of the initial level of unemployment and strictly positive, together with the law of motion for employment,

$$N_{t+1} = (1-\rho)N_t + \pi_t^{e|u}U_t = (1-\rho-\pi_t^{e|u})N_t + \pi_t^{e|u} = (1-\rho-\pi_t^{e|u})(1-U_t) + \pi_t^{e|u}.$$

Take two initial levels of unemployment, $\tilde{U}_0$ and U_0. Suppose $\tilde{U}_0 > U_0$, then, since $1-\rho > \pi_t^{e|u}$ for all t, $\tilde{U}_1 > U_1$. Moreover, if $\tilde{U}_t > U_t$, then $\tilde{U}_{t+1} > U_{t+1}$. Hence, $\tilde{U}_t > U_t$ for all t. Taking the derivative of the law of motion yields

$$\frac{\partial N_{t+1}}{\partial x} = (1-\rho-\pi_t^{e|u})\frac{\partial N_t}{\partial x} + \frac{\partial\pi_t^{e|u}}{\partial x}U_t.$$

Hence, $\frac{\partial \tilde{N}_1}{\partial x} > \frac{\partial N_1}{\partial x}$. In addition, $\frac{\partial \tilde{N}_{t+1}}{\partial x} > \frac{\partial N_{t+1}}{\partial x}$ if $\frac{\partial \tilde{N}_t}{\partial x} > \frac{\partial N_t}{\partial x}$. It follows that $\frac{\partial \tilde{N}_t}{\partial x} > \frac{\partial N_t}{\partial x}$ for all t.

To prove part ii), I show that the change in the job-finding probability in every period is increasing in w_0 if $\eta > 0.5$. We have from above, that

$$\begin{aligned}\frac{\partial^2 \pi_t^{e|u}}{\partial x \partial w_0} =& \frac{\partial \pi_t^{e|u}}{\partial w_0} \frac{1}{\pi_t^{e|u}} \frac{\partial \pi_t^{e|u}}{\partial x} \\ &+ \frac{\partial \pi_t^{e|u}}{\partial x} \left[\frac{(1-\alpha-\omega)a^\alpha}{1-\beta(1-\rho)} - \frac{\gamma^{t+1} w_0 z^{\frac{1}{\alpha-1}}}{1-\beta\gamma(1-\rho)} + \frac{\omega a^\alpha \gamma^{t+1}}{1-\gamma\beta(1-\rho)} \right]^{-1} \frac{\gamma^{t+1} z^{\frac{1}{1-\alpha}}}{1-\beta\gamma(1-\rho)}.\end{aligned}$$

We have that

$$\left. \frac{\partial \pi_t^{e|u}}{\partial w_0} \frac{1}{\pi_t^{e|u}} \right|_{x=0, w_0=\omega a^\alpha z^{\frac{1}{1-\alpha}}} = \frac{\eta-1}{\eta} \left[\frac{(1-\alpha-\omega)a^\alpha z^{\frac{1}{1-\alpha}}}{1-\beta\gamma(1-\rho)} \right]^{-1} \frac{\gamma^{t+1} z^{\frac{1}{1-\alpha}}}{1-\beta\gamma(1-\rho)}$$

such that

$$\left. \frac{\partial^2 \pi_t^{e|u}}{\partial x \partial w_0} \right|_{x=0, w_0=\omega a^\alpha z^{\frac{1}{1-\alpha}}} = \frac{2\eta-1}{\eta} \left[\frac{(1-\alpha-\omega)a^\alpha z^{\frac{1}{1-\alpha}}}{1-\beta\gamma(1-\rho)} \right]^{-1} \frac{\gamma^{t+1} z^{\frac{1}{1-\alpha}}}{1-\beta\gamma(1-\rho)} \frac{\partial \pi_t^{e|u}}{\partial x},$$

which is positive if $\eta > 0.5$.

A.5 Proof of Proposition 4

The welfare function is

$$W(\{c_t^F, c_t(s^t), \ell_t(s^t)\}) = \bar{\mu}^F \sum_{t=0}^{\infty} \beta^t u^F(c_t^F) + \sum_{t=0}^{\infty} \beta^t \sum_{s^t} u\left(c_t(s^t), \ell_t(s^t), s_t\right) \pi_t(s^t|s_0)\bar{\mu}(s_0).$$

We can equivalently express welfare as a function of aggregate consumption and individual consumption shares

$$\begin{aligned}\tilde{W}(\{v_t^F, v_t(s^t), \ell_t(s^t), C_t\}) =& \bar{\mu}^F \sum_{t=0}^{\infty} \beta^t u^F(v_t^F C_t) \\ &+ \sum_{t=0}^{\infty} \beta^t \sum_{s^t} u\left(v_t(s^t) C_t, \ell_t(s^t), s_t\right) \pi_t(s^t|s_0)\bar{\mu}(s_0),\end{aligned}$$

such that

$$
\begin{aligned}
\frac{\partial W}{\partial x} = \frac{\partial \tilde{W}}{\partial x} = & \sum_{t=0}^{\infty} \beta^t \bar{\mu}^F u_c^F(c_t^F) C_t \frac{\partial v_t^F}{\partial x} + \sum_{t=0}^{\infty} \beta^t \sum_{s^t} u_c(c_t(s^t)) C_t \frac{\partial v_t(s^t)}{\partial x} \pi_t(s^t|s_0) \bar{\mu}_0(s_0) \\
& + \sum_{t=0}^{\infty} \beta^t \sum_{s^t} u(c_t(s^t), \ell_t(s^t), s_t) \frac{\pi_t(s^t|s_0)}{\partial x} \bar{\mu}_0(s_0) \\
& + \sum_{t=0}^{\infty} \beta^t v_t^F u_c^F(c_t^F) \bar{\mu}^F \frac{\partial C_t}{\partial x} + \sum_{t=0}^{\infty} \sum_{s^t} \beta^t v_t(s^t) u_c(c_t(s^t)) \pi_t(s^t|s_0) \bar{\mu}(s_0) \frac{\partial C_t}{\partial x},
\end{aligned}
$$

which yields (1.27) with m_t defined as in the main text. Furthermore,

$$
C_t = z_t N_t^{1-\alpha} K_t^{\alpha} - \kappa_t \theta_t (1 - N_t) - K_{t+1} + (1 - \delta_k) K_t - I_t^G,
$$

such that

$$
\begin{aligned}
\sum_{t=0}^{\infty} \beta^t \mathrm{m}_t \frac{\partial C_t}{\partial x} = & \sum_{t=0}^{\infty} \beta^t \mathrm{m}_t \Bigg(N_t^{1-\alpha} K_t^{\alpha} \frac{\partial z_t}{\partial x} + (1-\alpha) z_t N_t^{-\alpha} K_t^{\alpha} \frac{\partial N_t}{\partial x} + \alpha z_t N_t^{1-\alpha} K_t^{\alpha-1} \frac{\partial K_t}{\partial x} \\
& + \kappa_t \theta_t \frac{\partial N_t}{\partial x} - \left(\frac{\partial \kappa_t}{\partial x} \theta_t + \kappa_t \frac{\partial \theta_t}{\partial x} \right) (1 - N_t) - \frac{\partial K_{t+1}}{\partial x} + (1 - \delta_k) \frac{\partial K_t}{\partial x} - \frac{\partial I_t^G}{\partial x} \Bigg) \\
= & \sum_{t=0}^{\infty} \beta^t \mathrm{m}_t \left(N_t^{1-\alpha} K_t^{\alpha} \frac{\partial z_t}{\partial x} - \frac{\partial I_t^G}{\partial x} \right) \\
& + \sum_{t=0}^{\infty} \beta^t \mathrm{m}_t \left(\left(\alpha z_t k_t^{\alpha-1} + 1 - \delta_k \right) \frac{\partial K_t}{\partial x} - \frac{\partial K_{t+1}}{\partial x} - \theta_t (1 - N_t) \frac{\partial \kappa_t}{\partial x} \right) \\
& + \sum_{t=0}^{\infty} \beta^t \mathrm{m}_t \left(\left[(1-\alpha) z_t k_t^{\alpha-1} + \kappa_t \theta_t \right] \frac{\partial N_t}{\partial x} - \kappa_t (1 - N_t) \frac{\partial \theta_t}{\partial x} \right)
\end{aligned}
$$

From the law of motion for employment, we get

$$
\kappa_t (1 - N_t) \frac{\partial \theta_t}{\partial x} = \left[\frac{\partial N_{t+1}}{\partial x} - (1 - \rho - q_t^v(\theta_t) \theta_t) \frac{\partial N_t}{\partial x} \right] \frac{\kappa_t}{(1-\eta) q_t^v(\theta_t)}
$$

Using this, we have

$$\begin{aligned}
\sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \frac{\partial C_t}{\partial x} &= \sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \left(N_t^{1-\alpha} K_t^{\alpha} \frac{\partial z_t}{\partial x} - \frac{\partial I_t^G}{\partial .x} \right) \\
&+ \sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \left(\left(\alpha z_t k_t^{\alpha-1} + 1 - \delta_k \right) \frac{\partial K_t}{\partial x} - \frac{\partial K_{t+1}}{\partial x} - \theta_t (1-N_t) \frac{\partial \kappa_t}{\partial x} \right) \\
&+ \sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \left(\left[(1-\alpha) z_t k_t^{\alpha-1} + \kappa_t \theta_t + \frac{1-\rho-q_t^v(\theta_t)\theta_t}{(1-\eta)q_t^v(\theta_t)}\kappa_t \right] \frac{\partial N_t}{\partial x} \right. \\
&\left. - \frac{\kappa_t}{(1-\eta)q_t^v(\theta_t)} \frac{\partial N_{t+1}}{\partial x} \right)
\end{aligned}$$

and with the equilibrium condition

$$\frac{\kappa_t}{q_t^v(\theta_t)} = \beta \left\{ (1-\alpha) z_{t+1} k_{t+1}^{\alpha} - w_{t+1} + (1-\rho) \frac{\kappa_{t+1}}{q_t^v(\theta_{t+1})} \right\}$$

we get

$$\begin{aligned}
\sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \frac{\partial C_t}{\partial x} &= \sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \left(N_t^{1-\alpha} K_t^{\alpha} \frac{\partial z_t}{\partial x} - \frac{\partial I_t^G}{\partial .x} \right) \\
&+ \sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \left(\left(\alpha z_t k_t^{\alpha-1} + 1 - \delta_k \right) \frac{\partial K_t}{\partial x} - \frac{\partial K_{t+1}}{\partial x} + \theta_t (1-N_t) \frac{\partial \kappa_t}{\partial x} \right) \\
&+ \sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \left(\left[(1-\alpha) k_t^{\alpha} z_t + \kappa_t \theta_t \right] \frac{\partial N_t}{\partial x} \right) - \sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \frac{\kappa_t \theta_t}{1-\eta} \frac{\partial N_t}{\partial x} \\
&- \sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \beta \left(\frac{(1-\alpha) k_{t+1}^{\alpha} z_{t+1} - w_{t+1}}{1-\eta} + \frac{(1-\rho)\kappa_{t+1}}{(1-\eta)q_t^v(\theta_{t+1})} \right) \frac{\partial N_{t+1}}{\partial x} \\
&+ \sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \frac{(1-\rho)\kappa_t}{(1-\eta)q_t^v(\theta_t)} \frac{\partial N_t}{\partial x}
\end{aligned} \tag{1.36}$$

Suppose the economy is in a steady state, then the average marginal utility of consumption $\mathrm{m}_t = v^F \bar{\mu}_0 + \frac{1}{C}\sum_{s_0} \bar{\mu}(s_0)$. Then, since $\frac{\partial N_0}{\partial x} = 0$,

$$\sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \frac{(1-\rho)\kappa_t}{(1-\eta)q_t^v(\theta_t)} \frac{\partial N_t}{\partial x} = \sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \frac{(1-\rho)\kappa_t}{(1-\eta)q_{t+2}^v(\theta_{t+1})} \frac{\partial N_{t+1}}{\partial x}$$

and the two terms cancel in equation (1.36). Furthermore, it follows from the optimal capital choice (see (1.18)) that $\alpha z_t k_t^{\alpha-1} + 1 - \delta_k = \frac{1}{\beta}$. Together with $\frac{\partial K_0}{\partial x} = 0$ this implies

$$\sum_{t=0}^{\infty}\beta^t \mathrm{m}_t \left(\left(\alpha z_t k_t^{\alpha-1} + 1 - \delta_k \right) \frac{\partial K_t}{\partial x} - \frac{\partial K_{t+1}}{\partial x} \right) = 0,$$

which simplifies equation (1.36) further and yields

$$\begin{aligned}\sum_{t=0}^{\infty}\beta^t m_t\frac{\partial C_t}{\partial x} =& \sum_{t=0}^{\infty}\beta^t m_t\left(N^{1-\alpha}K^{\alpha}\frac{\partial z_t}{\partial x}-\frac{\partial I_t^G}{\partial x}\right)-\sum_{t=0}^{\infty}\beta^t m_t\theta(1-N)\frac{\partial \kappa_t}{\partial x}\\ &+\sum_{t=0}^{\infty}\beta^t m_t\frac{1}{1-\eta}\left[w-\eta\left((1-\alpha)zk^{\alpha}+\theta\kappa\right)\right]M_{t+1}^{Inv}.\end{aligned}$$

The second term in the first line are the costs (or benefits) of changing vacancy posting costs. If posting costs are constant, the term drops out. The second line is the efficiency gain as defined in the main text. Since, the employment multiplier $M_{t+1}^{Inv} > 0$ is positive (proposition 1), the efficiency gain is positive if

$$w > \eta\left((1-\alpha)zk^{\alpha}+\theta\kappa\right) = w^*.$$

Appendix B Calibration Details

B.1 Estimation of job-finding and separation probabilities

The data source most commonly used to estimate transition rates between labor market states is the Current Population Survey (CPS). There are two main method to estimating the job-finding rate from CPS data. Here, I use the one based on gross flows, that is, I use the panel dimension of the monthly CPS microdata to estimate the number of workers who transition from unemployment to employment in a given month. The alternative approach uses only the aggregate time series of unemployment as described in Shimer (2012). It requires stronger assumptions than the gross flows method used here, in particular, it assumes a constant labor force. In contrast, the gross flows approach can be extended to incorporate more than two labor market states and arbitrary transitions between them. A discussion and comparison of the two methods can be found in Shimer (2012).

I consider two different definitions of unemployed workers, denoted U-3 and U-5 by the BLS. The most widely used concept is U-3. According to this definition a worker is unemployed if i) he or she does not work but has been actively looking for a job during the last four weeks and would be available to work or if ii) he or she is temporarily laid off and waiting to be recalled. The alternative definition, U-5, also encompasses workers who want a job, searched for a job at some point during the last twelve months, and could have taken a job in the last week if they had been offered one. Hence, this measure includes discouraged and marginally attached workers according to the BLS classification. Figure 1.B1 shows the number of unemployed workers according to the definitions U-3 and U-5 over time.

Following Shimer (2012), I estimate the job-finding probability from gross flows as follows:

- I match individuals across monthly CPS waves from January 1976 to December 2020 to obtain a panel data set
- For every month I compute the number of workers who transition between each of the three labor market states employed, unemployed, inactive
  - I do this for both concepts of unemployment, U-3 and U-5
  - The series are seasonally adjusted using X13-ARIMA-SEATS
- From these flows I obtain a Markov matrix for the monthly transition between the three states for every month in the sample
- I adjust for time aggregation using the method described in Shimer (2012)

  - I compute the continuous time Markov matrix (instantaneous transition probabilities) from the discrete time matrix and obtain the monthly transition probabilities from the instantaneous transition rates. The monthly probabilities obtained in this way capture the probability of experiencing a transition between state A and B over the course of one month. This is different from the probability of being in state B in the next month conditional on being in state A in the current month. The latter is what I observe in the data, the former is what I need to inform the calibration of the model.

- To also obtain separate transition probabilities for U-3 unemployed and marginally attached workers, I use the same procedure but with four states (employed, U-3 unemployed, marginally attached, inactive).

Prior to 1994, the CPS did not include the questions used to identify discouraged and marginally attached workers. This is why I can only compute job-finding probabilities of unemployed workers according to the broader definition U-5 for the time period from 1994 to 2020. For comparison, I also compute the transition probabilities according to the unemployment concept U-3 for the whole time period covered by the CPS, January 1976 to December 2020. Table 1.B1 shows the average monthly job-finding probability for U-3 unemployed, U-5 unemployed, and marginally attached workers for different time periods. For the time period from 1994 to 2020, the average job-finding probability for unemployed workers according to the concept U-3 was 29.4%. It was 2.5 percentage points lower for the group of U-5 unemployed workers. Marginally attached workers are much less likely to find a job in a given month, on average their job-finding probability is only 10.9%.

Table 1.B1: Average monthly transition probabilities, 1976–2020 and 1994–2020.

	1976–2020	1994–2020
Job-finding probability U-3	29.8	29.4
Job-finding probability U-5	—	26.9
Job-finding probability marginally attached	—	10.9
Separation rate	1.9	1.8

The reason for the small difference in job-finding probabilities between U-3 and U-5 can be found in Figure 1.B1, which shows the total numbers of unemployed workers according to definitions U-3 and U-5 and the number of marginally attached workers over time. On average, the number of marginally attached workers is only about one fifth of the number of U-3 unemployed workers. For the group of unemployed workers according to the definition U-5, marginally attached workers play a small role. This is why the substantially lower job-finding probability of marginally attached workers does not matter much for the overall job-finding probability in the group of U-5 unemployed workers.

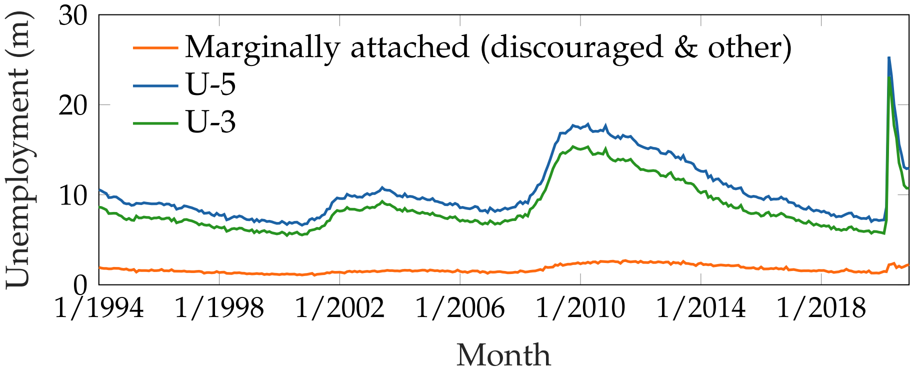


Figure 1.B1: Unemployment in the US, January 1994 to December 2020 (in millions).

Figure 1.B2 shows the estimated monthly job-finding probability over time. The dark blue line shows the estimated monthly job-finding probability of unemployed workers, when unemployed according to the concept U-3 are considered. For the time period from 1976Q1 to 2007Q2, I can compare the quarterly averages of this series to the series in Shimer (2012). The two are very similar, the standard deviation of the difference is less than 1.5 percentage points. This difference is likely coming from the different seasonal adjustment procedures used. The light blue line represents the job-finding probability for unemployed according to the definition U-5. Finally, the green line shows the job-finding rate for marginally employed workers, when I distinguish between four labor market states, employed, U-3 unemployed, marginally attached, and inactive.

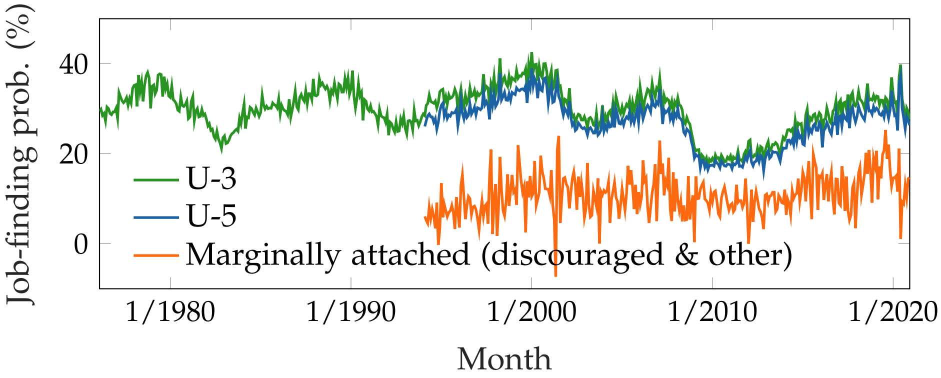


Figure 1.B2: Estimated monthly job-finding probabilities.

B.2 Calibration of disutility from effort

I calibrate the parameter χ to match the elasticity of the job-finding probability with respect to unemployment benefits $\epsilon_{q,b} = \frac{\mathrm{d}q^f}{\mathrm{d}b}\frac{b}{q^f}$. From the first-order condition for search effort, I have that

$$\ell^{\chi} = \beta\left(J_t(e) - J_t(u)\right)\frac{q^f}{\ell}. \tag{1.37}$$

In the steady state the difference between lifetime utility of employed and unemployed workers is

$$J_t(e) - J_t(u) = \frac{\log(\frac{w}{b}) - d_{0,e} + \frac{\ell^{1+\chi}}{1+\chi}}{1-\beta+\beta(\rho+q^f)}$$

Hence

$$\left(1-\beta+\beta(\rho+q^f)\right)\ell^{\chi} = \beta\left(\log\left(\frac{w}{b}\right) - d_{0,e} + \frac{\ell^{1+\chi}}{1+\chi}\right)x$$

where $x = \frac{q^f}{\ell}$ is a constant (partial equilibrium) and

$$\left(1-\beta+\beta(\rho+q^f)\right)\chi\ell^{\chi-1}\frac{\mathrm{d}\ell}{\mathrm{d}b} + \beta\frac{\mathrm{d}q^f}{\mathrm{d}b}\ell^{\chi} = -\beta\frac{1}{b}x + \beta\ell^{\chi}x\frac{\mathrm{d}\ell}{\mathrm{d}x}$$

Since, $\frac{\mathrm{d}\ell}{\mathrm{d}b} = \frac{\mathrm{d}q^f}{\mathrm{d}b}\frac{1}{x}$ Therefore

$$\left(1-\beta+\beta(\rho+q^f)\right)\chi\ell^{\chi-1}\frac{1}{x}\frac{\mathrm{d}q^f}{\mathrm{d}b} + \beta\frac{\mathrm{d}q^f}{\mathrm{d}b}\ell^{\chi} = -\beta\frac{1}{b}x + \beta\ell^{\chi}\frac{\mathrm{d}q^f}{\mathrm{d}b} \tag{1.38}$$

$$\Leftrightarrow \left(1-\beta+\beta(\rho+q^f)\right)\chi\ell^{\chi}\frac{\mathrm{d}q^f}{\mathrm{d}b}\frac{1}{q^f} = -\beta\frac{1}{b}x \tag{1.39}$$

$$\Leftrightarrow \left(1-\beta+\beta(\rho+q^f)\right)\chi\ell^{\chi}\frac{\mathrm{d}q^f}{\mathrm{d}b}\frac{b}{q^f} = -\beta\frac{q^f}{\ell} \tag{1.40}$$

Substituting (1.37) for ℓ^{χ} and rearranging yields

$$\chi = -\frac{1}{(1-\beta+\beta(\rho+q^f))\epsilon_{q,b}\left(J_t(e) - J_t(u)\right)}$$

All terms on the right-hand side follow directly from the calibration targets.

Appendix C Additional Theoretical Results

C.1 No-trade equilibrium and interest rate

I want to show that hand-to-mouth behavior can be the equilibrium outcome in an extended model in which households can save in a risk-free bond a_t at rate r_t, but are borrowing constrained. Consider the following generalization of the household problems described in the main text. Workers are excluded from participation in the equity and capital market where firm owners trade shares and rent out capital. A worker's budget constraint is

$$c_t(s_t) \leq (1-\tau_t) w_t \mathbb{1}_{s_t=e} + b_t \mathbb{1}_{s_t=u}(1+r_t)a_t - a_{t+1} \tag{1.41}$$

with borrowing constraint $a_{t+1} \leq 0$. Workers choose private consumption, effort, and bond holdings $\{c_t(s_t), \ell_t(s_t), a_{t+1}(s_t)\}_{t=0}^{\infty}$ to maximize expected lifetime utility subject to the budget constraint (1.41) and the borrowing limit $a_{t+1} \geq 0$. Observe that the wage depends on asset holdings a_t since it is determined by Nash bargaining and worker are risk averse such that their surplus from employment depends on their asset holdings. In other words, workers are in a better bargaining position if they hold more assets since they will be able to sustain a higher level of consumption during unemployment. See Krusell et al. (2010) for a more extensive discussion of this mechanism.

Firm owners also have access to the bond market where they can trade bonds with workers and with each other. I assume that all firm owners have the same endowments in period $t = 0$. Then, since the labor market is the only source of idiosyncratic risk and firm owners do not participate in the labor market, they are identical at all times. The representative firm owner chooses a sequence of consumption, bond holdings, investment, and capital $\{c_t^F, a_{t+1}^F, i_t^F, k_{t+1}^F\}_{t=0}^{\infty}$ to maximize expected lifetime utility given an initial endowment of bonds and shares (a_0^F, x_0^F)

$$\begin{aligned}
&\max_{\{c_t^F, a_{t+1}^F, i_t^F, k_{t+1}^F\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(c_t^F) \\
&\quad \text{s.t. } c_t^F \leq (1+r_t)a_t^F + \Pi_t^F - a_{t+1}^F + r_t^k k_t^F - T_t^F - \frac{\phi}{2}\left(\frac{i_t^F}{k_t^F} - \delta_k\right)^2 k_t^F - i_t^F, \\
&\quad k_{t+1}^F = (1-\delta_k)k_t^F + i_t^F, \\
&\quad a_{t+1}^F \geq 0, \quad k_{t+1}^F \geq 0.
\end{aligned}$$

No-trade equilibrium Since the gross supply of the bond is zero and households cannot borrow, it must hold in equilibrium that households do not save, $a_t = 0$. This requires that the interest rate is low enough.

Proposition 5. *Consider the extended model described above. In equilibrium, $a_t = 0$ and it holds* *for the equilibrium interest rate*

$$\begin{aligned} 1 + r_{t+1} \leq & \frac{1}{\beta}\left[\pi_t^{e|e} \frac{(1-\tau_t)w_t}{(1-\tau_{t+1})w_{t+1}}\right. \\ & \left. \times \left(1 + (1-\gamma)(1-\psi)\frac{\frac{w_{t+1}^N}{b_{t+1}} - 1 - (J_{t+1}(e) - J_{t+1}(u))}{1 + (1-\psi)(J_{t+1}(e) - J_{t+1}(u))}\right) + \pi_t^{u|e}\frac{(1-\tau_t)w_t}{b_{t+1}}\right]^{-1} \end{aligned} \tag{1.42}$$

Proof. Consider an employed worker in period t. The choice $a_{t+1} = 0$ is optimal only if

$$\begin{aligned} \frac{1}{(1-\tau_t)w_t} \geq & \beta\left[\pi_t^{e|e}\frac{1}{(1-\tau_{t+1})w_{t+1}}\left(1 + r_{t+1} + \frac{\partial w_{t+1}(a_{t+1})}{\partial a_{t+1}}(1+\tau_{t+1})\right)\right. \\ & \left. + \pi_t^{u|e}\frac{1 + r_{t+1}}{b_{t+1}}\right]. \end{aligned} \tag{1.43}$$

The derivative of the wage with respect to asset holdings, $\frac{\partial w_{t+1}}{\partial a_{t+1}}$, shows up because savings raise wages as they improve workers' bargaining position (Krusell et al. 2010). I now characterize this effect of savings on the wage. The Nash bargained wage is

$$w_t^N = \arg\max_w \psi \log\left(J_t^e(a,w) - J_t^u(a)\right) + (1-\psi)\log\left(J_t^F(w)\right),$$

where

$$\begin{aligned} J_t^e(a,w) = & \max_{a',\ell} \log\big(w(1-\tau_t) + (1+r_t)a - a'\big) \\ & + \beta\left[\pi_t^{e|e}(\ell)J_{t+1}^e(a',w') + \pi_t^{u|e}(\ell)J_{t+1}^u(a')\right] \end{aligned}$$

and

$$J_t^u(a) = \max_{a',\ell} \log\big(b_t + (1+r_t)a - a'\big) + \beta\left[\pi_t^{e|u}(\ell)J_{t+1}^e(a',w') + \pi_t^{u|u}(\ell)J_{t+1}^u(a')\right]$$

are the worker value functions of the extended model with savings.

The following first order condition implicitly defines the Nash wage

$$0 = F(w_t^N, a) \equiv (1-\psi)\left(J_t^e(a,w_t^N) - J_t^u(a)\right)\frac{w_t^N(1-\tau) + (1+r_t)a - a'}{1-\tau_t} - \psi\left(J_t^F(w_t^N)\right).$$

Its derivates with respect to the Nash-wage and asset are

$$\begin{aligned}\frac{\partial F(w_t^N,a)}{\partial w_t^N} =&(1-\psi)\left[\left(\frac{\partial J_t^e(a,w_t^N)}{\partial w_t^N}-\frac{\partial J_t^u(a)}{\partial w_t^N}\right)\frac{w_t^N(1-\tau)+(1+r_t)a-a'}{1-\tau}\right.\\ &\left.+J_t^e(a,w_t^N)-J_t^u(a)\right]-\psi\frac{\partial J_t^F(w_t^N)}{\partial w_t^N}\end{aligned}$$

and

$$\begin{aligned}\frac{\partial F(w_t^N,a)}{\partial a} =&(1-\psi)\left[\left(\frac{\partial J^e(w_t^N,a)}{\partial a}-\frac{\partial J^u(a)}{\partial a}\right)\frac{w_t^N(1-\tau)+(1+r_t)a-a'}{1-\tau}\right.\\ &\left.+\left(J_t^e(w_t^N,a)-J_t^u(a)\right)\frac{1+r_t}{1-\tau}\right].\end{aligned}$$

Using the implicit function theorem, it follows that

$$\frac{\partial w_t}{\partial a}=-(1-\gamma)\frac{(1-\psi)(1+r)}{1-\tau}\frac{1-(1-\tau_t)\frac{w_t^N}{b_t}+\left(J_t^e(w_t^N,a)-J_t^u(a)\right)}{1+(1-\psi)\left(J_t^e(w_t^N,a)-J_t^u(a)\right)}.$$

Substituting this into (1.43) with $a=0$ and $w_t^N=w_t$ yields

$$\begin{aligned}\frac{1}{(1-\tau_t)w_t} \geq&\beta\left(1+r_{t+1}\right)\left[\pi_t^{e|e}(\ell_t)\frac{1}{(1-\tau_{t+1})w_{t+1}}\right.\\ &\left.\times\left(1+(1-\gamma)(1-\psi)\frac{\frac{w_{t+1}^N}{b_{t+1}}-1-\left(J_{t+1}(e)-J_{t+1}(u)\right)}{1+(1-\psi)\left(J_{t+1}(e)-J_{t+1}(u)\right)}\right)+\pi_t^{u|e}(\ell_t)\frac{1}{b_{t+1}}\right].\end{aligned}$$

Solving for the interest rate gives,

$$\begin{aligned}1+r_{t+1} \leq&\frac{1}{\beta}\left[\pi_t^{e|e}\frac{(1-\tau_t)w_t}{(1-\tau_{t+1})w_{t+1}}\right.\\ &\left.\times\left(1+(1-\gamma)(1-\psi)\frac{\frac{w_{t+1}^N}{b_{t+1}}-1-\left(J_{t+1}(e)-J_{t+1}(u)\right)}{1+(1-\psi)\left(J_{t+1}(e)-J_{t+1}(u)\right)}\right)+\pi_t^{u|e}\frac{(1-\tau_t)w_t}{b_{t+1}}\right]^{-1}.\end{aligned}$$

Here, ℓ_t is the effort choice of unemployed workers in the equilibrium of the main text where saving is ruled out. For this interest rate, the necessary condition for optimality of $a_{t+1}=0$ is satisfied. □

For the calibration of the model, I assume that equation (1.42) holds with equality, i.e, the equilibrium interest rate is

$$\begin{aligned}1+r_{t+1} =& \frac{1}{\beta}\Bigg[\pi_t^{e|e}\frac{(1-\tau_t)w_t}{(1-\tau_{t+1})w_{t+1}} \times \left(1+(1-\gamma)(1-\psi)\frac{\frac{w^N_{t+1}}{b_{t+1}}-1-(J_{t+1}(e)-J_{t+1}(u))}{1+(1-\psi)(J_{t+1}(e)-J_{t+1}(u))}\right)\\ &+\pi_t^{u|e}\frac{(1-\tau_t)w_t}{b_{t+1}}\Bigg]^{-1}.\end{aligned} \tag{1.44}$$

This choice can be justified as the equilibrium interest rate in the limit as the supply of bonds goes to zero, which Werning (2015) labels the case of vanishing liquidity.

Condition (1.42) is only a necessary condition. It may not be sufficient for two reasons. First, it ensures that employed workers do not save, but unemployed workers might still do so if the job finding probability is high relative to the separation rate. In this case, unemployed workers have a stronger incentive to save than employed workers. We can obtain a condition similar to (1.42), that is necessary to rule out saving of unemployed workers. Second, because of the endogenous effort choice, households' expected utility is not necessarily concave in effort and assets. Starting from zero savings, a simultaneous increase in savings and decrease in effort may raise expected lifetime utility. Hence, I numerically verify that $a_t = 0$ is indeed an optimal choice for all households if the interest rate is given by (1.44).

C.2 Optimal allocation

In general, the equilibrium in the search and matching labor market described above is inefficient due to two congestion externalities. When posting a vacancy, a firm does not take into account the negative effect this has on the likelihood of other firms to fill their vacancies. Similarly, firms fail to internalize that every additional vacancy makes it easier for workers to find a job. As a result, the private benefits of posting a vacancy may exceed or fall below the social benefit.

To better understand how these inefficiencies shape the effects of government investment, I analyze the constrained-efficient allocation, which I define as the one that would be chosen by a utilitarian social planner who is constrained by the matching friction and faces the same capital adjustment costs as firm owners. To that end, I define social welfare as

$$W(\{c_t^F, c_t(s^t)\}) = \bar{\mu}^F \sum_{t=0}^{\infty}\beta^t c_t^F + \sum_{t=0}^{\infty}\beta^t \sum_{s^t} \log\left(c_t(s^t)\right) - d(\ell_t(s^t))\pi_t(s^t|s_0)\bar{\mu}(s_0),$$

where $\bar{\mu}^F$, $\bar{\mu}(e)$ and $\bar{\mu}(u)$ are the welfare weights of firm owners, initially employed and initially unemployed workers and $\pi_t(s^t|s_0)$ denotes the share of workers with history

$s^t = (s_0, s_1, \dots, s_t)$ in period t.

Definition 3 (Optimal allocation). *An optimal allocation for a given sequence of productivity is a collection of sequences of aggregate consumption, capital, employment, search effort and labor market tightness and of individual consumption and search effort which solves the planner problem*

$$\begin{aligned} \max_{\{C_t, N_{t+1}, K_{t+1}, L_t^u, \theta_t, c_t^F, c_t(s^t), \ell_t(s^t)\}} \quad & W(\{c_t^F, c_t(s^t)\}) \\ s.t.\ & C_t + K_{t+1} + \frac{\phi}{2}\left(\frac{K_{t+1}}{K_t} - 1\right)^2 K_t + \kappa_t \theta_t L_t^u \\ & = z_t K_t^{\alpha} N_t^{1-\alpha} + (1-\delta_k) K_t \\ & N_{t+1} = (1-\rho) N_t + q_t^v(\theta_t)\theta_t L_t^u \\ & C_t = \mu c_t^F + \sum_{s^t} c_t(s^t)\pi_t(s^t) \\ & L_t^u = \sum_{s^t | s_t = u} \ell_t(s^t)\pi_t(s^t) \\ & \textit{given } K_0,\ N_0. \end{aligned} \tag{1.45}$$

The planner takes the sequence of productivity as given. In other words, the sequence of public investment and thereby productivity has already been decided, and the planner now faces the problem of allocating the remaining resources.[19] The first constraint in the planner problem is the aggregate resource constraint. The right-hand side are total available resources consisting of output and capital after depreciation which can be spent on consumption, investment in next period's capital, and vacancy creation. The second constraint is the law of motion for employment. The planner can increase employment in the next period in two ways. First, the planner can raise tightness θ_t which comes at a resource cost according to the term $\kappa_t \theta_t L_t^u$ in the resource constraint since more vacancies have to be created for a constant level of aggregate search effort. Second, employment can be increased by raising aggregate search effort L_t^u with comes at a utility cost since effort enters the utility function, but there are also resource costs since more vacancies have to be created if tightness is to be held constant. The last two constraints of the planner problem state that individual consumption must add up to aggregate consumption and individual search effort $\ell_t(s^t)$ has to be consistent with aggregate search effort L_t^u.

The next propositions characterize the optimal allocation more closely.

Proposition 6 (Optimal allocation of capital). *The optimal allocation of capital satisfies*

$$1 + \phi\left(\frac{K_{t+1}}{K_t} - 1\right) = \beta\left(1 + \alpha z_{t+1} k_{t+1}^{\alpha-1} - \delta_k + \frac{\phi}{2}\left(\left(\frac{K_{t+2}}{K_{t+1}}\right)^2 - 1\right) - \frac{\partial \kappa_{t+1}}{\partial K_{t+1}} \theta_{t+1} L_{t+1}^u\right).$$

---

[19] The costs of public investment could be added to the resource constraint without changing the results that follow. This is because firm owners have linear utility.

Proof. The result follows immediately from the first-order conditions for consumption and capital associated with (1.45). □

If vacancy posting costs do not depend on capital, it holds that $\frac{\partial \kappa_{t+1}}{\partial K_{t+1}} = 0$ and the optimal path for the aggregate capital stock coincides with the equilibrium allocation given by equation (1.18). However, if vacancy posting costs depend on the aggregate capital stock, for example because they are proportional to labor productivity as would be needed for balanced growth, then the aggregate capital stock is too high in equilibrium because existing firms who rent capital do not take into account that more capital per match makes it more expensive for new firms to post a vacancy.

Next, I characterize the sequence of optimal tightness. It will depend on the elasticity of the vacancy filling probability with respect to tightness which I denote as $\eta \equiv -\frac{m'(\theta_t)\theta_t}{q_t^v(\theta_t)}$.

Proposition 7 (Optimal tightness with fixed search effort)**.** *Suppose individual search effort is fixed at $\ell_t(s^t) = 1$ and $d(1,u) = d(1,e)$, then optimal tightness satisfies*

$$\frac{\kappa_t}{q_t^v(\theta_t)} = \beta\left\{(1-\alpha)z_{t+1}k_{t+1}^{\alpha} - \eta\left[(1-\alpha)z_{t+1}k_{t+1}^{\alpha} + \kappa_{t+1}\theta_{t+1}\right] + (1-\rho)\frac{\kappa_{t+1}}{q_{t+1}^v(\theta_{t+1})}\right\}.$$

Comparison with the equilibrium condition (1.7) shows that without search effort, the equilibrium is constrained efficient if the wage is

$$w_t = \eta\left[(1-\alpha)z_t k_t^{\alpha} + \kappa_t\theta_t\right] \tag{1.46}$$

This is the standard condition for efficiency in the DMP model.

Proposition 8 (Optimal tightness)**.** *Suppose that the welfare weights of initially unemployed and employed workers are equal to their population shares, $\bar{\mu}(s) = \pi_0(s)$, then optimal tightness satisfies*

$$\begin{aligned}\frac{\kappa_t}{q_t^v(\theta_t)} =\beta\Bigg\{&(1-\alpha)z_{t+1}k_{t+1}^{\alpha} - \eta\left[(1-\alpha)z_{t+1}k_{t+1}^{\alpha} + \kappa_{t+1}\theta_{t+1}\ell_{t+1}(u)\right] \\ &+ (1-\eta)\frac{\mu}{\bar{\mu}^F}\left(d(\ell_{t+1}(u),u) - d(0,e)\right) + (1-\rho)\frac{\kappa_{t+1}}{q_{t+1}^v(\theta_{t+1})}\Bigg\},\end{aligned}$$

where the optimal level of individual search effort solves

$$d'(\ell_t(u),u) = \frac{\bar{\mu}^F}{\mu}\kappa_t\theta_t\frac{1}{1+\eta}.$$

In this case, the constrained-efficient allocation is implemented if the wage amounts to

$$w_t = \eta \left[(1-\alpha) z_t k_t^{\alpha} + \kappa_t \theta_t \ell_t(u)\right] - (1-\eta) \frac{\mu}{\bar{\mu}^F} \left(d(\ell_t(u), u) - d(0, e)\right). \tag{1.47}$$

The differences to the optimal wage in the case without effort given by equation (1.46) are intuitive. First, the term $\kappa_t \theta_t$ is multiplied by individual search effort $\ell_t(u)$. To see why, suppose optimal search effort increases. Then, firms find it easier to fill a vacancy and expand vacancy creation. To prevent an inefficiently high vacancy creation, the wage has to be higher to discourage vacancy creation. Second, the additional summand in (1.47) takes into account the difference in disutility of effort between employed and unemployed. If the disutility is higher for unemployed, a lower level of unemployment is desirable which is implemented through a lower wage leading to a higher level of labor market tightness.

C.3 News shock

The preceding discussion has highlighted the role of expectation about future productivity for the employment effect of public investment. The importance of expected future productivity can also be seen when comparing the public investment employment effect to the change in employment that would result from a permanent change in productivity, defined as follows.

Definition 4 (Employment effect of (future) productivity). *Let $N_t(\mathcal{Y}_0, z_0, z_1, \dots)$ denote employment in period t in an equilibrium with initial conditions $\mathcal{Y}_0 = (N_0, w_0, K_0)$ and productivity sequence $\mathcal{Z} = (z_t)_{t=0}^{\infty}$. Consider a permanent increase in productivity in period T. The employment effect in t is defined as*

$$M_t^z(T, \mathcal{Y}_0, \mathcal{Z}) = \frac{\partial N_t(\mathcal{Y}_0, \dots, z_{T-1}, x z_T, x z_{T+1}, \dots)}{\partial x}|_{x=1}.$$

I get the following result

Proposition 9. *If the economy is in its steady state initially, then*

$$M_t^{Inv}(T, \mathcal{X}_0, \mathcal{I}^G) = \frac{\vartheta}{1-\beta(1-\delta_G)(1-\rho)} \frac{\delta_G}{I^G} M_t^z(T, \mathcal{Y}_0, \mathcal{Z}).$$

The public investment employment effect is proportional to the employment change in response to a permanent change in future productivity where the factor of proportionality depends on the elasticity of productivity with respect to public investment. For private agents, the announcement of the public investment expansion constitutes a news shock about productivity and, up to a constant factor, induces the same employment response.

Proof. Consider the productivity sequence $(z_k)_{k=0}^{\infty}$ with $z_k = z$ for $k < t$ and $z = xz$ for

$k \geq T$. The wage in period s is

$$w_s = \begin{cases} \gamma^s w_0 + (1-\gamma)\omega a^\alpha z^{\frac{1}{1-\alpha}} \frac{\gamma^s - 1}{\gamma - 1}, & \text{if } s < T \\ \gamma^s w_0 + (1-\gamma)\omega a^\alpha z^{\frac{1}{1-\alpha}} \left(\frac{\gamma^s - \gamma^{s-T+1}}{\gamma - 1} + x^{\frac{1}{1-\alpha}} \frac{\gamma^{s-T+1} - 1}{\gamma - 1} \right), & \text{if } s \geq T \end{cases}$$

and for $k < T$

$$\begin{aligned} \pi_k^{e|u} =& \zeta^{\frac{1}{\eta}} (1-\rho)^{\frac{1-\eta}{\eta}} \left(z^{\frac{1}{1-\alpha}} \kappa a^\alpha \right)^{\frac{\eta-1}{\eta}} \\ & \times \left[\sum_{s=k}^{T-1} (\beta(1-\rho))^{s-k} (1-\alpha) a^\alpha z^{\frac{1}{1-\alpha}} + \sum_{s=T}^{\infty} x^{\frac{1}{1-\alpha}} (\beta(1-\rho))^{s-k} (1-\alpha) a^\alpha z^{\frac{1}{1-\alpha}} \right. \\ & - \sum_{s=k}^{\infty} (\beta(1-\rho))^{s-k} \gamma^s w_0 + \sum_{s=k}^{T-1} (\beta(1-\rho))^{s-k} \omega a^\alpha z^{\frac{1}{1-\alpha}} (\gamma^s - 1) \\ & + \sum_{s=T}^{\infty} (\beta(1-\rho))^{s-k} \omega a^\alpha z^{\frac{1}{1-\alpha}} (\gamma^s - \gamma^{s-T+1}) \\ & \left. + \sum_{s=T}^{\infty} (\beta(1-\rho))^{s-k} \omega a^\alpha z^{\frac{1}{1-\alpha}} x^{\frac{1}{1-\alpha}} (\gamma^{s-T+1} - 1) \right]^{\frac{1-\eta}{\eta}} \end{aligned}$$

which can be simplified to

$$\begin{aligned} \pi_k^{e|u} =& \zeta^{\frac{1}{\eta}} (1-\rho)^{\frac{1-\eta}{\eta}} \left(z^{\frac{1}{1-\alpha}} \kappa a^\alpha \right)^{\frac{\eta-1}{\eta}} \\ & \left\{ \frac{(1-\alpha-\omega) a^\alpha z^{\frac{1}{1-\alpha}}}{1-\beta(1-\rho)} \left[1 + (\beta(1-\rho))^{T-k} (x^{\frac{1}{1-\alpha}} - 1) \right] \right. \\ & \left. + \gamma \frac{\omega a^\alpha z^{\frac{1}{1-\alpha}}}{1-\gamma\beta(1-\rho)} (\beta(1-\rho))^{T-k} (x^{\frac{1}{1-\alpha}} - 1) - \frac{\gamma^k}{1-\gamma\beta(1-\rho)} (w_0 - \omega a^\alpha z^{\frac{1}{1-\alpha}}) \right\}^{\frac{1-\eta}{\eta}} \end{aligned}$$

I have that for $k < T$

$$\begin{aligned} \frac{\partial \pi_k^{e|u}}{\partial x}|_{x=1} =& \pi_k^{e|u} \frac{1-\eta}{\eta} \frac{1}{1-\alpha} \left\{ \frac{(1-\alpha-\omega) a^\alpha z^{\frac{1}{1-\alpha}}}{1-\beta(1-\rho)} \right. \\ & \left. - \frac{\gamma^k}{1-\gamma\beta(1-\rho)} (w_0 - \omega a^\alpha z^{\frac{1}{1-\alpha}}) \right\}^{-1} (\beta(1-\rho))^{T-k} \\ & \left(\frac{(1-\alpha-\omega) a^\alpha z^{\frac{1}{1-\alpha}}}{1-\beta(1-\rho)} + \gamma \frac{\omega a^\alpha z^{\frac{1}{1-\alpha}}}{1-\gamma\beta(1-\rho)} \right), \end{aligned}$$

If the wage in period 0 is at its steady state value $w_0 = \omega a^\alpha z^{\frac{1}{1-\alpha}}$, I have for $k < T$

$$\frac{\partial \pi_k^{e|u}}{\partial x}|_{x=1} = (\beta(1-\rho))^{T-k} \pi_k^{e|u} \frac{1-\eta}{\eta} \frac{1}{1-\alpha} \left(1 + \frac{\omega\gamma}{1-\omega-\alpha} \frac{1-\beta(1-\rho)}{1-\gamma\beta(1-\rho)} \right) > 0.$$

Note that $1-\omega-\alpha>0$ if $\pi_k^{e|u}>0$. The short-run employment effect is

$$\begin{aligned} M_t^z(T,\mathcal{Y}_0,\mathcal{Z}) =& (1-N_0)\frac{\partial \pi_0^{e|u}}{\partial x} = (1-N_0)(\beta(1-\rho))^T \pi_0^{e|u}\frac{1-\eta}{\eta}\frac{1}{1-\alpha} \\ & \times \left(1+\frac{\omega\gamma}{1-\gamma\beta(1-\rho)}\frac{1-\beta(1-\rho)}{1-\omega-\alpha}\right) \end{aligned}$$

If the economy is at the steady state initially, then the employment effect is

$$\begin{aligned} M_t^z(T,\mathcal{Y}_0,\mathcal{Z}) &= \sum_{k=0}^{t-1}(1-\rho-\pi^{e|u})^{t-k-1}(1-N)\frac{\partial \pi_k^{e|u}}{\partial x} \\ &= (\beta(1-\rho))^{T+1-t}(1-N)\pi^{e|u}\frac{1}{1-\alpha}\frac{1-\eta}{\eta}\frac{1-((1-\rho-\pi^{e|u})\beta(1-\rho))^t}{1-((1-\rho-\pi^{e|u})\beta(1-\rho))} \\ &\times \left(1+\frac{\omega\gamma}{1-\gamma\beta(1-\rho)}\frac{1-\beta(1-\rho)}{1-\omega-\alpha}\right). \end{aligned}$$

The result then follows from the formula for the employment multiplier of public investment (1.24). □

Appendix D Additional Quantitative Results

Table 1.D2: Business cycle moments with cross-correlations.

		U	Y	Inv	Wages	Lab. prod.	z
Standard deviation		0.081 (0.101)	0.017 (0.015)	0.090 (0.065)	0.008 (0.010)	0.011 (0.012)	0.012 (0.012)
Autocorrrelation		0.848 (0.943)	0.846 (0.845)	0.248 (0.821)	0.947 (0.744)	0.789 (0.761)	0.791 (0.797)
Corr. with …	U	1.000 (1.000)	-0.931 (-0.858)	-0.674 (-0.800)	-0.594 (-0.300)	-0.836 (0.127)	-0.882 (-0.345)
	Y	-	1.000 (1.000)	0.761 (0.878)	0.703 (0.553)	0.973 (0.624)	0.983 (0.788)
	inv	-	-	1.000 (1.000)	0.276 (0.455)	0.760 (0.595)	0.808 (0.756)
	wages	-	-	-	1.000 (1.000)	0.717 (0.012)	0.618 (0.012)
	lab. prod.	-	-	-	-	1.000 (1.000)	0.985 (0.872)
	z	-	-	-	-	-	1.000 (1.000)

Data moments in parentheses. Variables are relative deviations from the HP trend with smoothing parameters 1,600. We use quarterly data from 1951q1 to 2019q4.

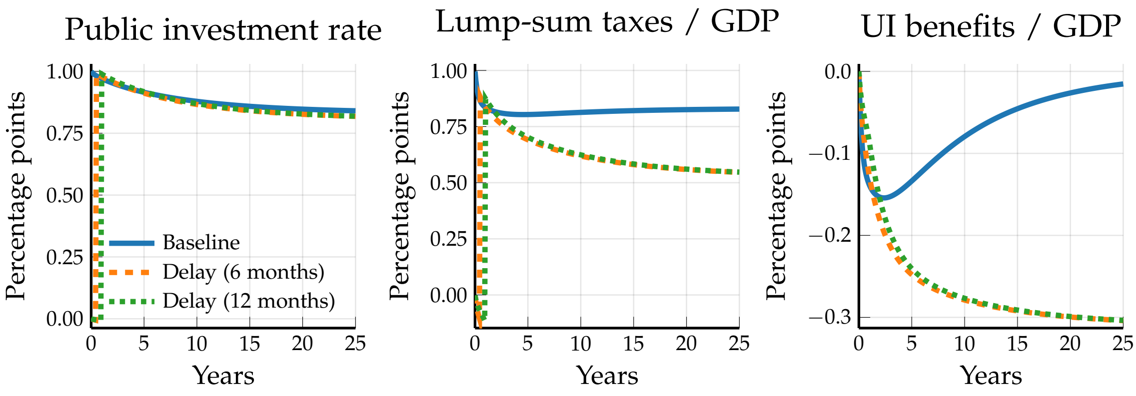


Figure 1.D3: The fiscal response to the public investment expansion.

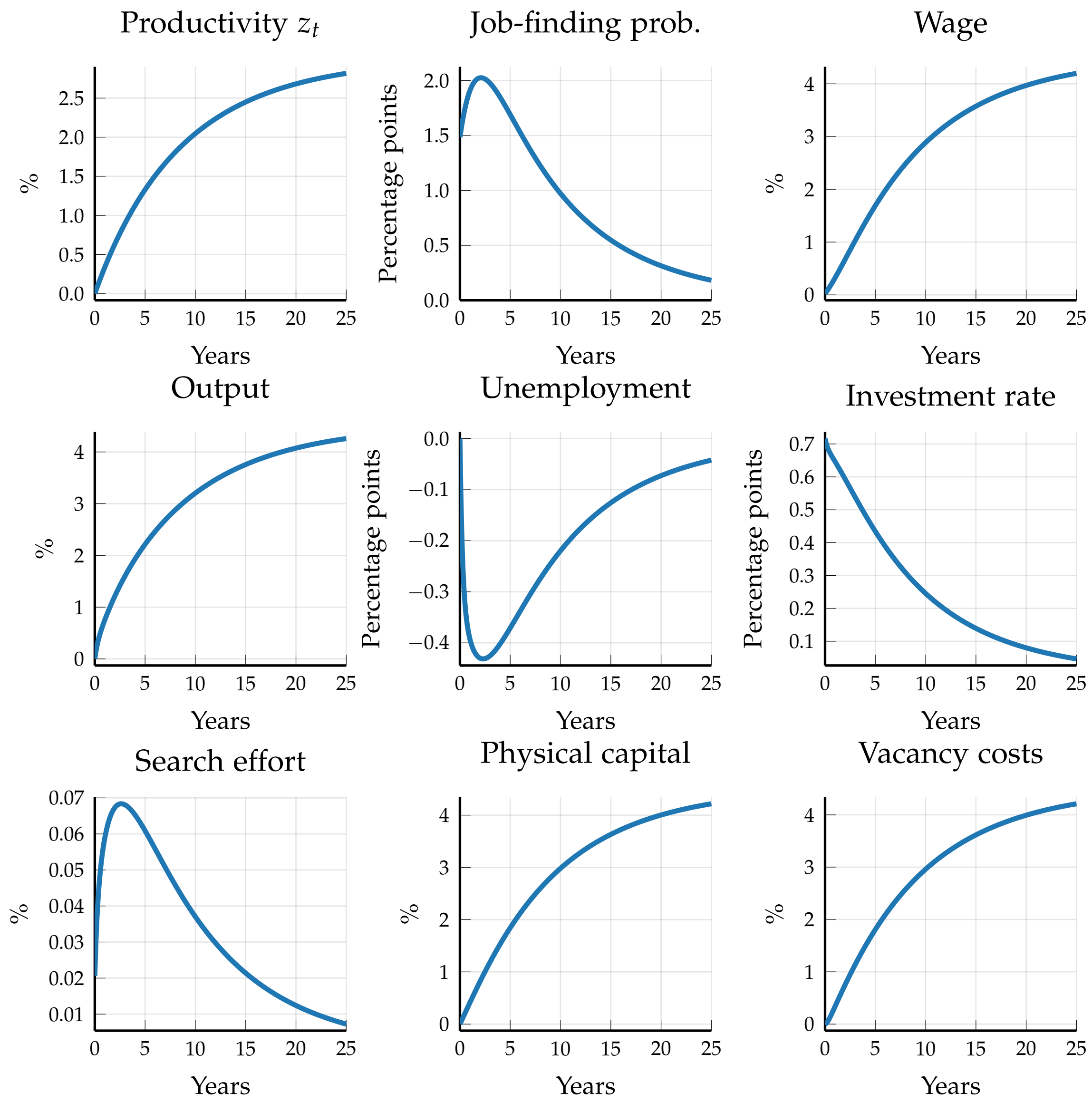


Figure 1.D4: Long-run responses to a government investment program.

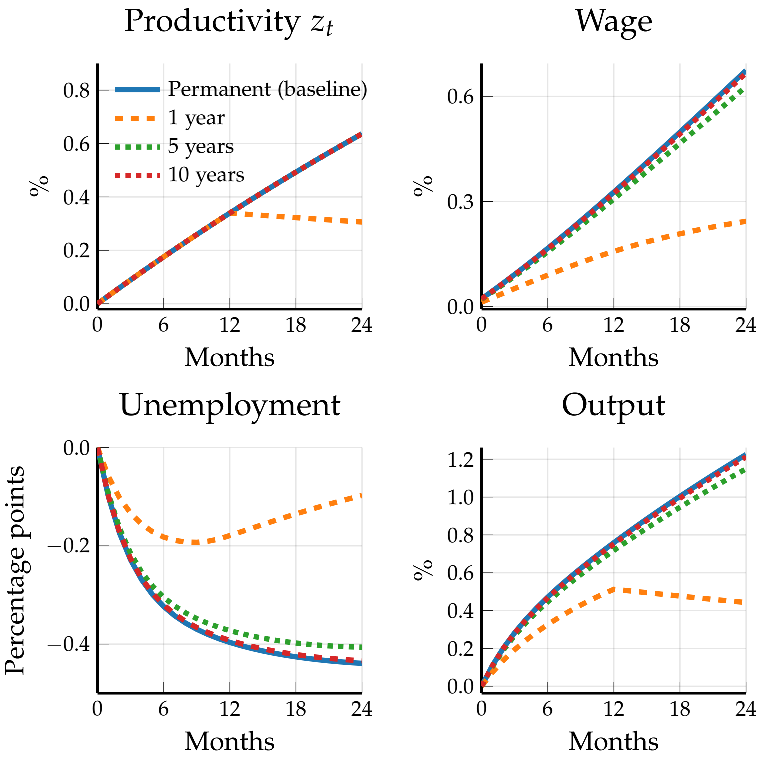


Figure 1.D5: Responses to transitory expansion in public investment.

Table 1.D3: Output multipliers of public investment at different horizons for different scenarios.

		1 year	2 years	3 years	Long run
Peak	baseline	0.71	1.18	1.57	4.52
	6 months delay	0.47	0.98	1.40	4.52
	12 months delay	0.24	0.76	1.22	4.52
	recession	0.79	1.23	1.61	4.52
	labor tax financed	0.54	0.98	1.36	4.42
Cumulative	baseline	0.41	0.69	0.93	4.52
	6 months delay	0.45	0.66	0.88	4.52
	12 months delay	—	0.66	0.84	4.52
	recession	0.48	0.76	0.98	4.52
	labor tax financed	0.30	0.54	0.76	4.42

Notes: The peak multiplier is the maximum change in output divided by the change in public investment over the respective horizon H, $\max_{h\leq H} \frac{\Delta Y_h}{\Delta I_h^G}$. The cumulative multiplier is the cumulative change in output over horizon H divided by the cumulative change in oublic investment over the same horizon, $\frac{\sum_{h\leq H} \Delta Y_h}{\sum_{h\leq H} \Delta I_h^G}$.

D.1 State dependence for TFP induced recession and boom

In the main text, I study the state dependence of the employment effect of public investment considering a recession that results from a joint positive shock to the separation rate and the wage level (and vice-versa for a boom). Here, I alternatively consider a recession due to a negative shock to productivity of one standard deviation,

$$\log A_0 = -0.0056$$

and accordingly, for a boom

$$\log A_0 = +0.0056,$$

after which productivity A_t evolves according to (1.32).

Figure 1.D6 show the response of TFP, unemployment, labor market tightness and wages.

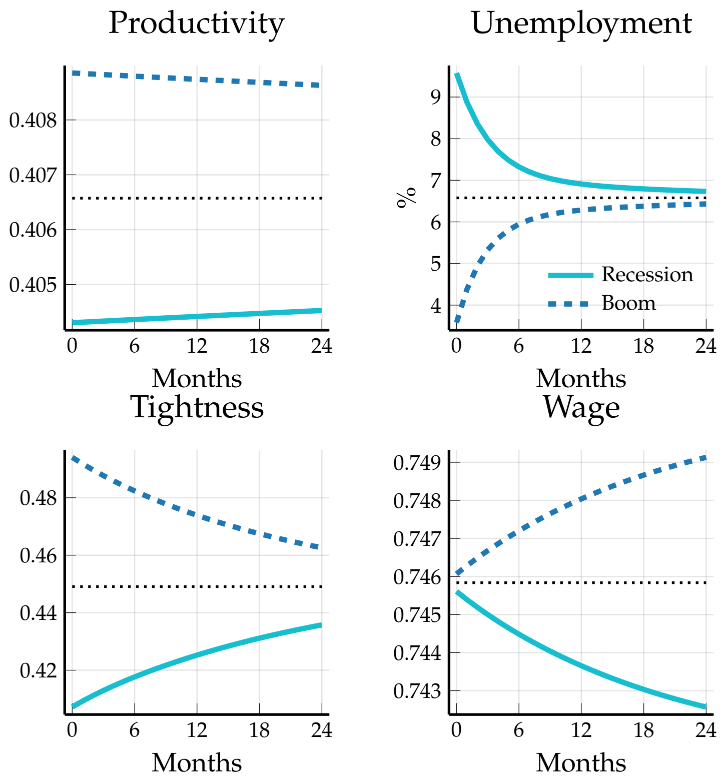


Figure 1.D6: Responses to productivity shocks.

Qualitatively, I obtain the same result as in the main text—the employment effect of public investment is larger in a recession.

D.2 Alternative parameterizations

For the baseline calibration I have chosen the bargaining power of workers ψ such that the labor share is 64% as in the data. Alternatively, I could require that the bargaining

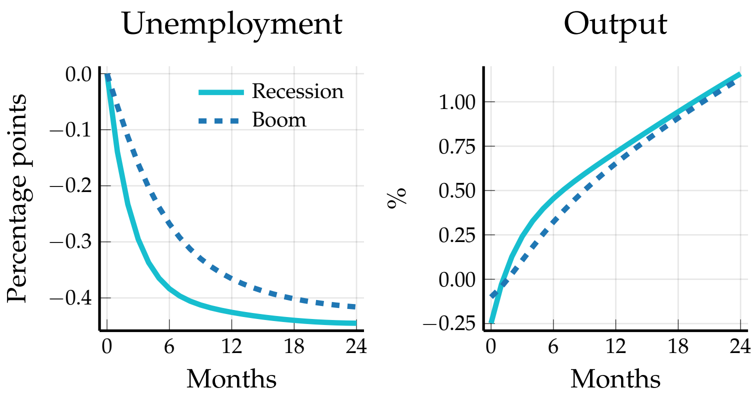


Figure 1.D7: Responses of unemployment and output to permanent expansion in public investment in recession and boom.
Notes: Shown are the deviations from the paths without an expansion in public investment (see Figure 1.D6)

power is such that vacancy creation is efficient in the steady state, i.e., the wage is given by (1.47). Note that the right term in (1.47) is zero in the steady state given our calibration strategy. The employment and wage response for a re-calibration of the model that requires workers bargaining power to implement efficient vacancy creation in steady state is shown by the dashed red line in Figure 1.D8.

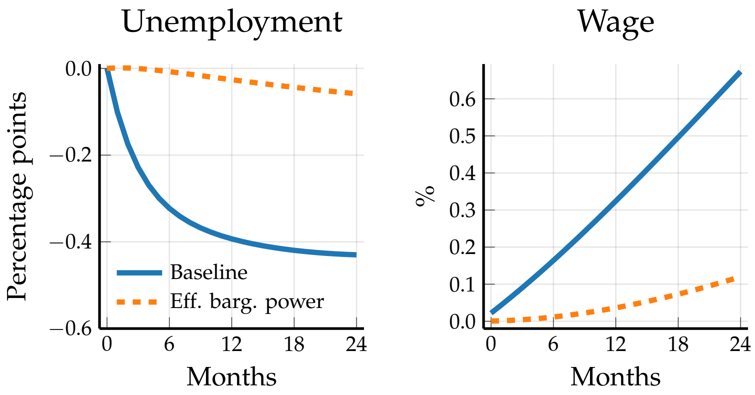


Figure 1.D8: Response if bargaining power implements efficient vacancy creation in steady state.
Notes: Dashed red line: response of unemployment for calibration where workers' bargaining power is chosen to implement efficient level of vacancy creation in steady state.

Our baseline specification assumes that posting costs are proportional to labor productivity. The dotted red line in Figure 1.D9 shows the short-run response of unemployment and wages if posting costs are constant instead. The dashed orange line shows the responses when capital adjustment costs are zero. The dashed green line shows the responses when capital adjustment costs are infinite, i.e., the private capital stock is constant.

Figure 1.D10 varies the degree of wage stickiness.

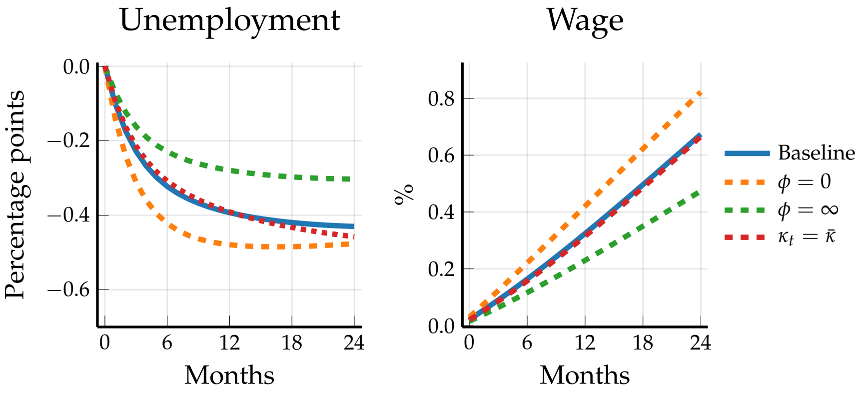


Figure 1.D9: Responses without capital adjustment costs and with constant vacancy posting costs.

Notes: Dashed orange line: no capital adjustment costs. Dashed green line: infinite capital adjustment costs. Dotted red line: constant posting costs.

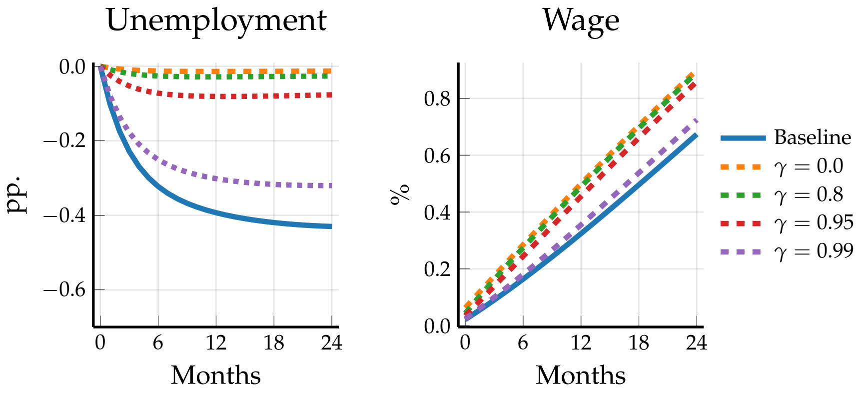


Figure 1.D10: Responses for different degrees of wage stickiness.

Chapter 2

Does Wealth Inequality Affect the Transmission of Monetary Policy?

This chapter is joint work with Johannes Wacks.

Disclaimer: This chapter uses data from the Eurosystem Household Finance and Consumption Survey. The results published and the related observations and analysis may not correspond to results or analysis of the data producers.

1 Introduction

In the US, but also in other advanced economies, wealth inequality has risen considerably since the mid-1980s. In general, wealth inequality displays significant variation both over time and across space.[1] At the same time, recent advances in macroeconomics have led to a new discussion about the role of inequality for macroeconomic outcomes. In particular, several models predict that the wealth distribution is important for understanding the transmission of monetary policy.[2] We contribute to this debate by documenting empirically that wealth inequality affects the strength of the monetary transmission mechanism to the real economy. We provide three separate pieces of evidence, each showing that monetary policy has larger real effects when wealth inequality in the population is higher. To the best of our knowledge, we are the first to offer a detailed account of this relationship.

Macroeconomists have long neglected wealth inequality when studying monetary policy. This was largely due to the complexity and computational demands of structural models that feature a non-degenerate wealth distribution. However, quantitative

---

[1] See, for instance, Hubmer et al. (2021) for the evolution of wealth inequality in the US over the past century, Piketty (2014) for a detailed account of worldwide inequality, and the graphs and statistics we provide in this study.

[2] Examples are Gornemann et al. (2016), Kaplan et al. (2018), Auclert (2019), Luetticke (2021), Bilbiie (2020), and Werning (2015).

research also supported the view that the distribution of wealth had little importance for macroeconomic dynamics (Krusell and Smith 1998). Recently, however, this view has been challenged, and the question of how "inequality matters for macro" (Ahn et al. 2018) has received new attention.

Several mechanisms have been proposed through which wealth inequality can affect the transmission of monetary policy. Luetticke (2021) finds that greater wealth inequality mutes the response of aggregate investment and amplifies that of consumption, with the overall effect on output approximately canceling out. The reason is that wealthy households with high marginal propensities to invest benefit from contractionary monetary policy, whereas incomes of asset-poor households with high marginal propensities to consume fall. Building on the observation that wealthier households are more likely to invest in stocks, Melcangi and Sterk (2020) argue that, when the rich hold a greater share of wealth, an interest rate cut leads to a stronger rebalancing towards equities. This results in a stock market and investment boom and hence an amplification of the output response. In Chapter 3, we obtain the same result in a model in which rich entrepreneurs invest strongly into their private firm in response to an interest rate decline due to a portfolio rebalancing motive. Here, we ask whether there is a state dependence of monetary policy transmission on wealth inequality in the data that would support the predictions of these studies.

We tackle the question of how wealth inequality alters the transmission of monetary policy in three ways. We first use separate aggregate time series data for the US and the UK, and show that the effects of monetary policy are state-dependent. To this end, we estimate state-dependent local projections, as suggested by Auerbach and Gorodnichenko (2013), using the top 10% wealth share as a state variable. In the US and the UK, we find that in regimes of high inequality monetary policy had a larger impact on real activity than in regimes of low inequality. The differences are quantitatively important. In the US, while industrial production contracted by up to 2 percent in times of high wealth inequality in response to a 25 basis points (bp) increase in the federal funds rate, it shows no statistically significant contraction in times of low inequality. In the UK, responses of output and unemployment to monetary policy are smaller overall but, as in the US, they are relatively larger in times of high wealth inequality.

While the appeal of our first approach is its simplicity and the availability of high-quality data at the aggregate level, the drawback is that we cannot rule out that other variables that have co-moved with wealth inequality over time drive our results. Therefore, we turn to cross-sectional analyses in the second part of our study, which allows us to control for confounding factors. We use estimates provided by the Internal Revenue Service (IRS) on total wealth held by the richest households in each US state to construct measures of state-level wealth inequality. In line with the results on the aggregate level, we find that both output and unemployment in US states that display more wealth inequality react more strongly to common monetary policy shocks. In a third step, we construct measures of wealth inequality for Euro Area countries using data from the ECB's Household Finance and Consumption Survey (HFCS). We find that Euro Area countries with high levels of inequality react more strongly to common monetary policy shocks.

Based on the consistent findings in all three settings and after conducting various robustness checks, we conclude that higher wealth inequality is correlated with a stronger transmission of interest rate changes to the real economy. The strength of this correlation differs between the set-ups we study. Regarding the output response, we estimate the largest effect on the US aggregate level. Here, an increase in the top 10% share by one percentage point is associated with a 0.26 percentage points stronger average contraction in industrial production over the first three years after a 25 bp monetary policy shock. The effect is about 0.02 percentage points in the UK and about 0.05 in the cross section of Euro Area countries. Across US states, we find that a one percentage point increase in the top 1% share comes with an increase in the response of state personal income by 0.013 percentage points.[3] The effect of an increase in the top 10% wealth share by one percentage point on the average response of the unemployment rate ranges from 0.018 percentage points on the US aggregate level to 0.041 in the Euro Area. In the cross section of US states, an increase in the top 1% share by one perecentage point raises the unemployment response by 0.005 percentage points. These numbers point to an economically meaningful effect of wealth inequality on the transmission of monetary policy to the real economy.

The reduced-form evidence that we provide in this study can inform and discipline the design of future structural models that analyze monetary policy in the framework of heterogeneous agent models. It is also relevant for the current debate among policymakers about when and by how much to raise interest rates. Given the high levels of wealth inequality observed in many developed countries at the moment, our results indicate that a rate increase would have relatively strong effects on the real economy.

The remainder of our paper is structured as follows. Below, we review related literature. We study the state-dependent effects of monetary policy on the aggregate level in Section 2. In Section 3 we analyze the cross-section of US states, and in Section 4 we turn to a cross-section of Euro Area countries. In Section 5 we conclude.

Related Literature We follow a long tradition of studies that have analyzed the effects of monetary policy empirically using time series methods on an aggregate level (Ramey 2016; Christiano et al. 2005, 1999; Coibion 2012). In particular, in Section 2 we use state-dependent local projections to estimate the dependence of monetary policy transmission on the distribution of wealth. This approach has been advocated by Ramey and Zubairy (2018) and Auerbach and Gorodnichenko (2013), who ask whether government multi-

---

[3] At the US state level, due to data limitations, we only estimate the impact of the top 1% wealth share on monetary policy transmission, not of the top 10% wealth share as in the other sections of this study.

pliers are larger or smaller during times of economic slack. In the context of monetary policy, state-dependent local projections have been used by Ascari and Haber (2022), Tenreyro and Thwaites (2016), and Alpanda and Zubairy (2019). Most closely related to our study is Alpanda and Zubairy (2019), who find that high levels of household debt mute the effects of interest rate changes. We corroborate this finding in Section 4, but show that wealth inequality influences the strength of monetary policy transmission even when controlling for the debt-to-GDP ratio. Lastly, the study of Brinca et al. (2016) is close to ours. They ask how the size of fiscal multipliers depends on wealth inequality and find that higher inequality is associated with larger multipliers.

Our analysis of US states in Section 3 is similar to Carlino and DeFina (1998, 1999) and Owyang and Wall (2009). Their findings suggest a role for the industrial composition in a state as well as the share of small firms in affecting the effectiveness of monetary policy. We add wealth inequality as an additional explanatory variable, which we construct based on estate tax returns.[4] Our analysis on Euro Area countries in Section 4 is related to Almgren et al. (forthcoming) who find that countries in which many households hold few liquid assets react more strongly to monetary policy. While we can validate their results in our set-up, we take a somewhat broader perspective by focusing on wealth inequality, and find a significant effect of wealth inequality even when controlling for other explanatory variables. Slacalek et al. (2020) also investigate the effects of monetary policy shocks in the Euro Area but have a different focus than we do. They only study the four largest economies and decompose their responses to monetary policy shocks using structural models. In contrast, we look at all Euro Area countries and keep to a reduced-form analysis.

We are not aware of empirical studies that analyze the dependence of monetary policy transmission on wealth inequality, but several authors have investigated the reverse question, i.e., to what extent monetary policy affects inequality. For instance, Coibion et al. (2017) find that expansionary monetary policy tends to lower inequality in income and consumption, though they do not study wealth inequality as an outcome variable because of data limitations. Adam and Zhu (2016) draw similar conclusions using Euro Area survey data from the HFCS. In contrast, Andersen et al. (2021) who use administrative household-level data from Denmark, find that expansionary monetary policy increases inequality.

---

[4] Estate tax returns have been used before to construct measures of wealth inequality at the US aggregate level (Kopczuk and Saez 2004; Kopczuk 2015; Saez and Zucman 2016).

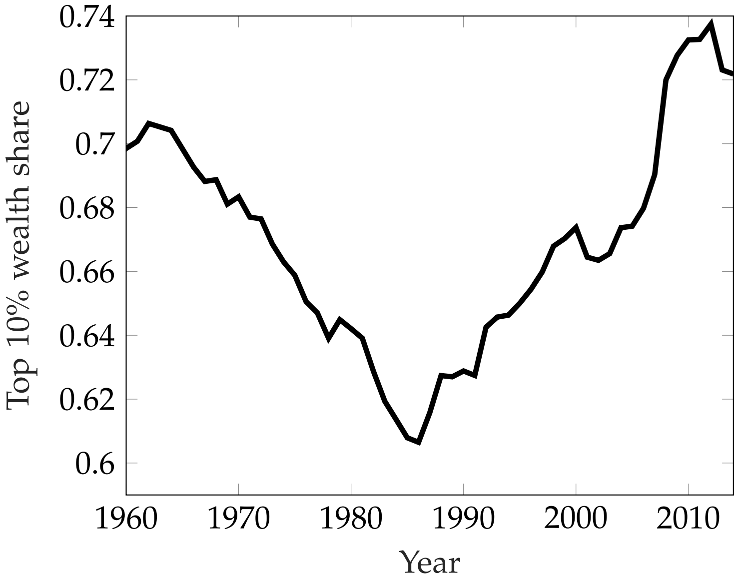


Figure 2.1: Top 10% wealth share in the US, data from the World Inequality Database.

2 Evidence from State-Dependent Local Projections

2.1 United States

We obtain measures of wealth inequality for the US from Piketty et al. (2018), made publicly available via the World Inequality Database (WID). Piketty et al. (2018) follow the approach in Saez and Zucman (2016) to estimate the wealth distribution. They define household wealth as the current market value of all assets owned by the household net of all its debt and estimate household wealth primarily by capitalizing income tax data.[5]

As our benchmark measure of inequality we use the wealth share held by the top 10% of the wealth distribution. The 90th percentile of the wealth distribution roughly separates the "wealth middle class" and the very wealthy and is therefore a statistic commonly used to assess the degree of wealth inequality in a given population (Alvaredo et al. 2018). Figure 2.1 shows the U-shaped evolution of the wealth share of the richest 10% over time. It peaked in 1962 at 71%, declined to 61% until 1986, and rose from then on, reaching 74% in 2012.

In this section we use time series data on US aggregate variables to assess how wealth inequality among households affects the transmission of monetary policy.[6] We estimate state-dependent local projections (Jordà 2005; Auerbach and Gorodnichenko 2013). For

---

[5] See Saez and Zucman (2016) for a detailed discussion of the definition of wealth used and the capitalization approach.

[6] The aggregate time series data for the US and the UK are taken from the Federal Reserve Economic Database (FRED).

each horizon $h \in [0, 1, \ldots, H]$, we estimate the following model:

$$\begin{aligned} y_{t+h} = \alpha_h + \beta_h \cdot i_t + \beta_h^+ \cdot (\text{ineq}_t \cdot i_t) \\ + \sum_{p=1}^{P} \Gamma_{h,p} \cdot X_{t-p} + \sum_{p=1}^{P} \Gamma_{h,p}^+ \cdot \left(\text{ineq}_t \cdot X_{t-p}\right) + u_{t+h}, \end{aligned} \tag{2.1}$$

where y_t is an outcome variable of interest (e.g., the log of industrial production), i_t is the federal funds rate, ineq_t is our measure of wealth inequality, X_t is a vector of control variables and u_t is an error term with $\mathbb{E}[u_t] = 0$.

The non-standard elements in equation (2.1) are the interaction terms between inequality and the interest rate, i_t, and between inequality and the controls, X_t. We introduce them to capture the potential dependence between wealth inequality and the effects of monetary policy on the real economy.[7] Conditional on a specific value of inequality at time t, $\left(\beta_h + \beta_h^+ \cdot \text{ineq}_t\right)$ gives the response of y to a 100 basis points increase in the interest rate h months after it occurred. In times of low inequality, the response of y_t to a change in the federal funds rate is primarily governed by the parameters β_h. As inequality rises, the parameters β_h^+ become increasingly important in determining the response of y_t.

To make our results comparable to the empirical literature on monetary policy shocks, our baseline specification follows Ramey (2016). In particular, we use data at monthly frequency, α_h collects a constant and a linear time trend, we set $P = 2$, and we include as controls in X_t the log of industrial production, the unemployment rate, the log of the consumer price index and the commodity price index, as well as the federal funds rate. As our inequality measure is only available at annual frequency, we assign each month of a given year that year's observation. Since the top 10% share moves relatively slowly, other forms of interpolation lead to virtually the same results. We estimate impulse response functions (IRFs) up to a horizon of $H = 36$ months.

We instrument the federal funds rate with an exogenously identified monetary policy shock series, i.e., we estimate IV local projections as proposed by Stock and Watson (2018). We employ the narratively identified monetary policy shock series from Romer and Romer (2004), which has been further extended by Coibion et al. (2017). Romer and Romer (2004) use narrative and quantitative records of meetings of the Federal Open Market Committee (FOMC) to derive a measure of intended changes in the federal funds rate around FOMC meetings. They then regress this measure on the Federal Reserve's internal forecasts of several aggregate variables. The residuals of this projection are then used as monetary policy shocks as they are relatively free of endogenous responses of

---

[7] Instead of assuming a simple linear interaction term we have also experimented with more complicated, so-called "transition functions" $F(\text{ineq}_t)$, that map the degree of inequality into a value between zero and one as in Auerbach and Gorodnichenko (2013). The results were very similar to the ones shown here, which is why we opt for the more parsimonious specification using the linear interaction term, i.e., we set $F(\text{ineq}_t) = \text{ineq}_t$.

the central bank to the state of the economy. As an instrument for the interaction term between inequality and the interest rate we use the product of the contemporaneous Romer & Romer shock and previous year's level of inequality, i.e., we lag inequality by one year. This ensures that a possible contemporaneous correlation between shocks and inequality does not bias the estimates of β_h^+.[8] The major advantage of this shock series for our purposes is that it begins as early as 1969m3 such that our sample encompasses two time periods of relatively high wealth inequality (the 1960s and the 2000s), and a period of relatively low inequality in the 1980s (see Figure 2.1).

Auerbach and Gorodnichenko (2013) stress that local projections offer important advantages in the context of modeling state dependence relative to other time series methods, such as Smooth Transition Vector Autoregressions (STVAR). Most importantly, when using local projections to produce impulse responses to a monetary policy shock for a given value of inequality at time t, one does not have to assume a path for inequality over the considered horizon. Rather, an IRF at horizon h gives the *average* response of y_{t+h} to a monetary policy shock that occurred at an inequality level of ineq_t. For instance, a systematic, endogenous response of wealth inequality to monetary policy as suggested by the results in Coibion et al. (2017), is not ruled out when estimating impulse responses. This stands in stark contrast to the IRFs constructed from an STVAR, where one has to make an assumption on how inequality evolves over the considered horizon of the IRF.

Figure 2.2 shows the estimated response of industrial production to a 25 bp shock to the federal funds rate. IRFs for other variables can be found in Figure 2.A1 in Appendix A.2. Focus first on the dashed black line in Figure 2.2. It depicts the unconditional response of industrial production to a monetary policy shock. We obtain it by estimating equation (2.1), but leaving out the interaction terms with inequality, i.e., we impose that there is no dependence on wealth inequality. We obtain the familiar result that a contractionary monetary policy shock depresses real activity in the economy, especially so at horizons between one and two years. The shape and the magnitude of the IRF are well in line with previous empirical results (Ramey 2016).

Next we allow the effects of monetary policy to be state-dependent, i.e., we reintroduce the interaction terms with inequality in equation (2.1). The blue line depicts the IRF when a monetary policy shock hits the economy during a regime of low inequality, the red line when it hits during a regime of high inequality. Low and high inequality refer to the first and third quartile of observed wealth inequality values in our sample (a top 10% wealth share of 62.9% and 67.0% respectively). The shaded areas indicate 90% confidence intervals constructed from Newey and West (1987) standard errors.

The core finding is that the IRFs in the two regimes are markedly different. On the one hand, the real effects of interest rate movements were strong during times of high

---

[8] Coibion et al. (2017) find a positive relationship between monetary policy shocks and income inequality, but they do not consider wealth inequality. See also Appendix A.1.

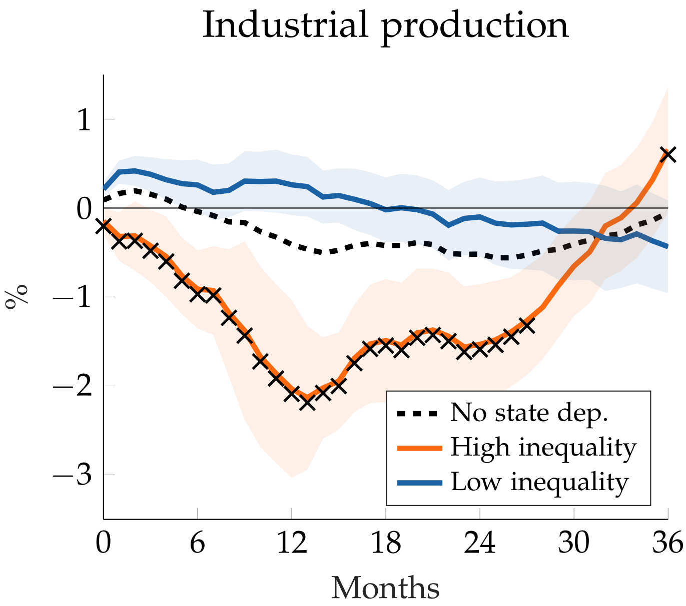


Figure 2.2: IRF of industrial production to 25 bp change in federal funds rate.
Notes: Black dashed: No state dependence. Blue: Regime of low inequality (first quartile of observed inequality). Red: Regime of high inequality (third quartile). Shaded areas are 90% confidence intervals based on Newey and West (1987) standard errors. Black crosses indicate horizons at which we can reject equality of the IRFs at 90% confidence level ($H_0 : \beta_h^+ = 0$).

inequality, leading to a contraction of industrial production by up to 2.1%. During times of low inequality, on the other hand, real activity was hardly affected by monetary policy. At short horizons we even obtain significant positive responses to a supposedly contractionary shock.[9] The IRF then approaches zero and later becomes negative, but it is never statistically significant. On average, the estimated response in the high inequality regime is 1.1 percentage points larger than in the low inequality regime over the first three years. Given the difference in the top 10% wealth share between the two regimes of 4.1 percentage points, an increase in this measure of inequality by one percentage point is associated with a 0.26 percentage points larger average contraction of industrial production in the first three years.

We can formally test whether the effects of monetary policy are independent of wealth inequality with a series of t-tests on the parameters β_h^+ for $h \in [0, 1, \ldots, H]$. At the horizons indicated by the black crosses in Figure 2.2, we can reject the null hypothesis that $\beta_h^+ = 0$ at a 90% confidence level. We can reject the hypothesis that there is no state dependence at all horizons during the first two years after the shock.

Figure 2.3 shows the reaction of the unemployment rate to a monetary policy shock. It mirrors the response of industrial production. While unemployment barely rises after the shock under low inequality, there is a pronounced spike in unemployment if the shock takes place in a regime of high wealth inequality. Moreover, we find statistically

---

[9] The positive response at short horizons owes to some extent to the fact that we do not make any recursivity assumption in equation (2.1). As we show in the robustness checks, imposing recursivity leads to negative or insignificant responses at short horizons even in a regime of low inequality.

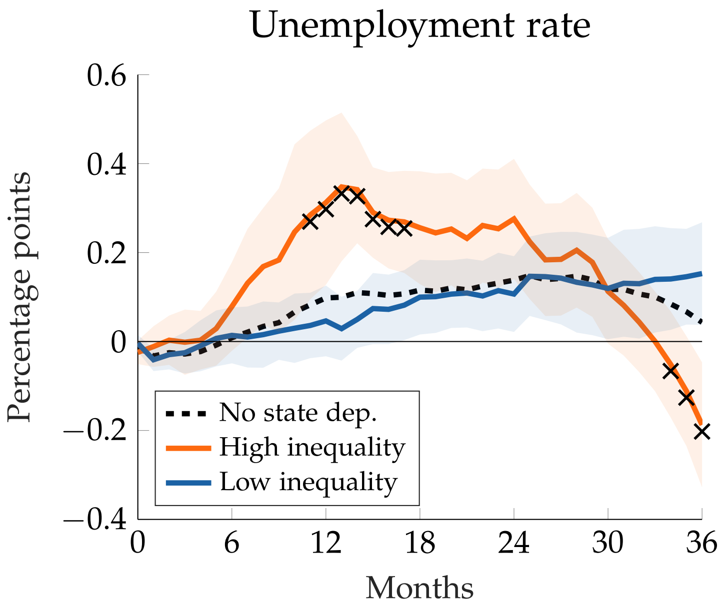


Figure 2.3: IRF of the unemployment rate to 25 bp change in federal funds rate.
Notes: Black dashed: No state dependence. Blue: Regime of low inequality (first quartile of observed inequality). Red: Regime of high inequality (third quartile). Shaded areas are 90% confidence intervals based on Newey and West (1987) standard errors. Black crosses indicate horizons at which we reject equality of the IRFs at 90% confidence level ($H_0 : \beta_h^+ = 0$).

significant state dependence at several horizons in the first and second year after the shock. Using the same back-of-the-envelope calculation as before, our results indicate that the unemployment response becomes on average 0.02 percentage points larger when the top 10% wealth share grows by one percentage point.

The relationship between the two regimes switches at very long horizons as was the case for industrial production. One potential explanation for this pattern is that at late horizons the local projections pick up the beginning of the next phase of the business cycle. This would account for a more pronounced boom at large horizons under high inequality after the shock caused a more pronounced recession at shorter horizons.

Could it be that the endogenous reaction of the monetary authority is driving the differential results? For instance, the Federal Reserve might lower its rate faster in times of low inequality in response to a contractionary shock, thereby stimulating real activity. Figure 2.4 shows that this is not the case. It depicts the IRF of the federal funds rate. Over the first six months the responses are not statistically different from each other in the two regimes. At longer horizons, the reaction of the Federal Reserve becomes more accommodating in a regime of high inequality.

Robustness We assess the robustness of our results in several ways. For brevity, we show the corresponding IRFs of industrial production in Appendix A.2. First, we use different measures of inequality, namely the Gini coefficient and the top 1% wealth share. While the results using the Gini index are nearly identical to the baseline results (Figure 2.A2), when we use the top 1% share (Figure 2.A3) the absolute differences between the

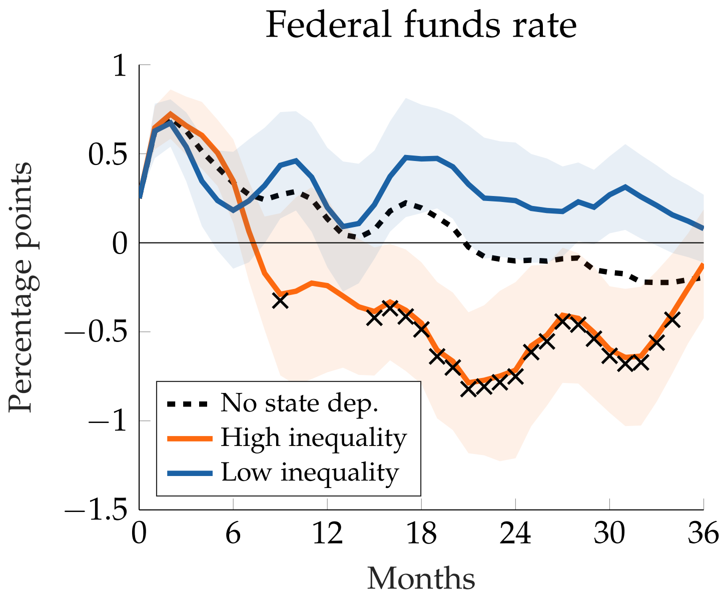


Figure 2.4: IRF of federal funds rate to 25 bp change in federal funds rate.

Notes: Black dashed: No state dependence. Blue: Regime of low inequality (first quartile of observed inequality). Red: Regime of high inequality (third quartile). Shaded areas are 90% confidence intervals based on Newey and West (1987) standard errors. Black crosses indicate horizons at which we reject equality of the IRFs at 90% confidence level ($H_0 : \beta_h^+ = 0$).

two regimes' IRFs become even larger.

Second, traditional identification schemes for monetary policy shocks based on timing restrictions have assumed that industrial production, unemployment, and the price level do not respond contemporaneously to changes in the federal funds rate (see, for instance, Christiano et al. 1999). We can impose this recursivity by including contemporaneous values of log industrial production, unemployment, and the log of the price indices in equation (2.1) (Ramey 2016). As Figure 2.A4 shows, assuming recursivity dampens the positive response of industrial production at short horizons, but it remains the case that the response is stronger when inequality is high.

Third, Coibion (2012) argues that IRFs to monetary policy shocks derived from Romer & Romer shocks are sensitive to the inclusion of the early 1980s. During this time period the Federal Reserve targeted non-borrowed reserves and the federal funds rate was a less suitable measure of the monetary policy stance. We check the robustness of our results by excluding this time period, i.e., we use only the years 1984 to 2007 in our sample. As Figure 2.A5 shows, our results qualitatively still hold for this subperiod, even though the dependence on wealth inequality is statistically significant at fewer horizons.

Lastly, we also consider the Chicago Fed National Activity Index (CFNAI) instead of log industrial production as the measure of real economic activity. The results are shown in Figure 2.A6. While the results are not as stark as for industrial production, there are still several horizons in the first year at which the response is significantly stronger during times of high inequality. At very long horizons, however, the relationship reverses, which to some extent was also the case when using industrial production as the measure

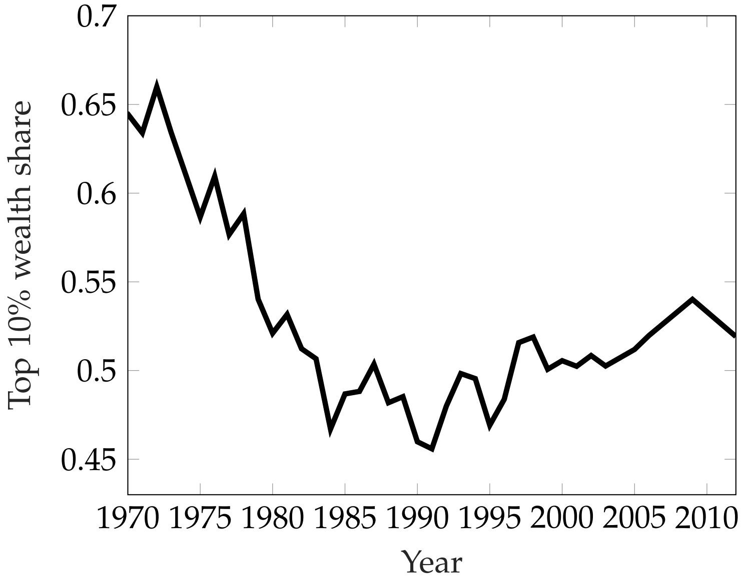


Figure 2.5: Top 10% wealth share in the UK, data from the World Inequality Database.

of economic activity.

2.2 United Kingdom

In this section, we show that the positive relationship between wealth inequality and the real effects of monetary policy also holds in the UK. The WID provides the data from Alvaredo et al. (2016) on the top 10% wealth share in the UK. We plot it in Figure 2.5. As in the US, the top 10% wealth share over time exhibits a u-shape, but the rise in inequality since the mid 1980s was much smaller in the UK than in the US. As an instrument for the monetary policy rate set by the Bank of England (BOE) we use the narratively identified shock series by Cloyne and Hürtgen (2016). They adopt the Romer and Romer (2004) methodology to identify monetary policy surprises in the UK between 1975m1 and 2007m12.

Figures 2.6 and 2.7 show the estimated IRFs for industrial production and unemployment. Unconditionally, i.e., without the interaction terms with inequality, a contractionary monetary policy shock lowers industrial production and raises unemployment one to two years after its occurrence. While the dynamics are similar to those in the US, the magnitude of the responses is smaller in the UK, but well in line with those depicted in Cloyne and Hürtgen (2016).

Turning to the state dependence of monetary policy transmission, we obtain qualitatively similar results as for the US. At most horizons, changes in the interest rate tend to have more pronounced effects on real activity in times of high inequality, although the relationship is reversed at a few points during the first year. The absolute differences between high- and low-inequality responses, however, are a bit smaller in the UK. We plot the IRFs conditional on the minimum and the maximum observed level of inequality in

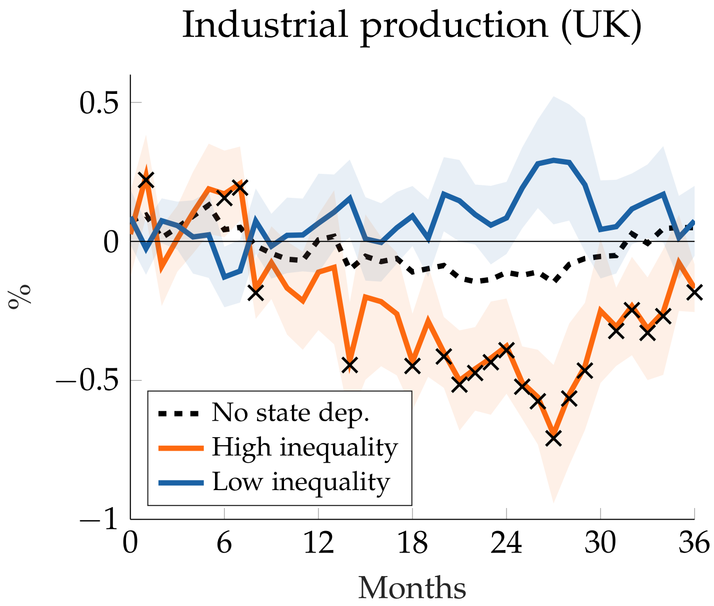


Figure 2.6: IRF of UK industrial production to 25 bp change in BOE policy rate.
Notes: Black dashed: No state dependence. Blue: Regime of low inequality (minimum of observed inequality). Red: Regime of high inequality (maximum). Shaded areas are 90% confidence intervals based on Newey and West (1987) standard errors. Black crosses indicate horizons at which we reject equality of the IRFs at 90% confidence level ($H_0 : \beta_h^+ = 0$).

our sample (a top 10% share of 45.6% and 61.0% respectively). An interest rate change that occurs in the so defined high-inequality regime lowers industrial production by up to 0.7% and raises unemployment by 0.16 percentage points. In contrast, under low inequality neither industrial production nor unemployment show pronounced deviations from zero at the considered horizons. In sum, an increase in the top 10% wealth share by one percentage point is associated with a 0.02 percentage points larger fall of industrial production over the first three years after the shock, and a 0.006 percentage points larger rise in unemployment.

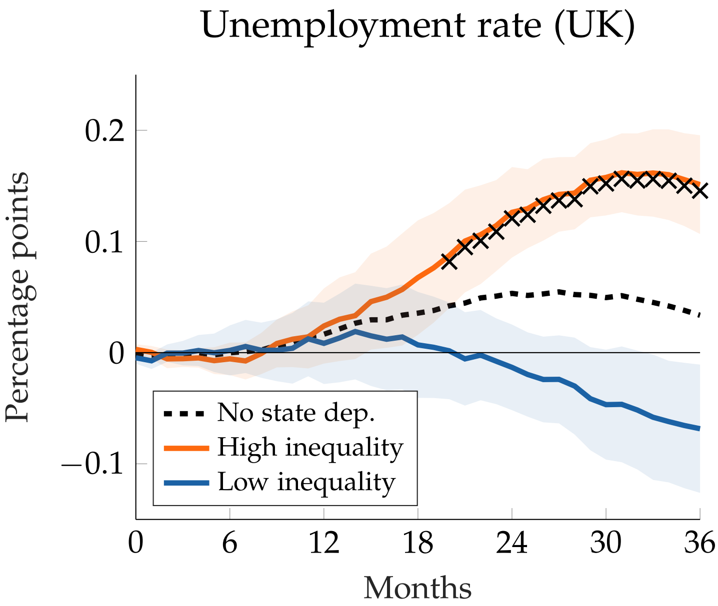


Figure 2.7: IRF of UK unemployment to 25 bp change in BOE policy rate.
Notes: Black dashed: No state dependence. Blue: Regime of low inequality (minimum of observed inequality). Red: Regime of high inequality (maximum). Shaded areas are 90% confidence intervals based on Newey and West (1987) standard errors. Black crosses indicate horizons at which we reject equality of the IRFs at 90% confidence level ($H_0 : \beta_h^+ = 0$).

3 Cross-Sectional Evidence from US States

In this section, we document that state personal income and unemployment respond more strongly to interest rate changes in US states with higher wealth inequality. To this end, we estimate the effect of interest rate changes on personal income and unemployment by state and then regress the estimated effects on states' level of wealth inequality. The advantage of this cross-sectional strategy over the time series approach in the previous section is that it allows us to control for confounding factors. Any variable that evolved in the same u-shape as the top 10% wealth share over the last decades could be responsible for our findings of state dependence in the previous section. In the following, we rule out many alternative explanations by controlling for these variables. The second reason for taking a cross-sectional approach is that the series of wealth inequality by US states that we construct in the next subsection has a low frequency. Between 1969 (when the Romer & Romer shock series begins) and 1986, we observe inequality only twice for every state, and afterwards tri-annually. This precludes a time series analysis as we performed it on the national level where we observed inequality annually. Before we describe the empirical strategy in greater detail, we discuss the construction of the series of wealth inequality by state in the next subsection.

3.1 A measure of wealth inequality at the US state level

To measure wealth inequality at the state level we resort to publicly available data on top wealth holders derived from estate tax returns. The federal estate tax was introduced in 1916 and is a tax on the transfer of wealth from the estate of a deceased person to its beneficiaries. A tax return must be filed by every deceased US citizen whose gross estate, valued on the date of death, equals or exceeds a certain exemption level, which has varied over time (see Jacobson et al. (2007) for a historical overview and detailed description of the federal estate tax). Data on federal estate tax returns have previously been used for research on wealth inequality (Kopczuk and Saez 2004; Kopczuk 2015; Saez and Zucman 2016), but to the best of our knowledge not for a state-level analysis.

Based on estate tax returns, the Internal Revenue Service (IRS) periodically publishes estimates on the total wealth held by so-called top wealth holders. Top wealth holders are defined as those currently alive US citizens for whom an estate tax return would be required upon death given the current exemption level regarding estate taxes. To arrive at the estimates of total wealth held by this group of individuals the IRS uses the estate multiplier technique. In short, every observed estate tax return is inflated by the inverse probability of that person dying in a given year. Therefore, old people (with relatively high probabilities of dying) receive low weights and young people receive high weights. This way, the IRS arrives at an estimate of the total wealth held by the wealthiest part of the population (see Kopczuk and Saez (2004) and Jacobson et al. (2007) for a detailed description of the methodology).

The IRS provides estimates on the total wealth held by top wealth holders for each US state in its Statistics of Income (SOI) Bulletins for the years 1976, 1982, and then every three years from 1986 onward. Given the total wealth held by top wealth holders and the number of top wealth holders, we construct the share of wealth held by the richest 1% of citizens for each state and year that is available. Appendix A.3 lays out the details of this procedure. The key assumption that we make to arrive at our estimates is that at any given point in time and in each US state, the right tail of the wealth distribution follows a Pareto distribution (Hubmer et al. 2021; Kopczuk and Saez 2004; Benhabib et al. 2015). We construct top 1% shares here, instead of top 10% shares, since the exemption level for filing estate taxes has risen significantly over the recent decades and often times only covers a fraction of the wealthiest 1% of citizens. Extrapolating from this information to the wealth share of the top 10% is therefore difficult, and studies that use estate tax income for constructing inequality measures typically only report wealth shares of the top 1% or of even smaller fractions.

3.2 Empirical strategy

The approach we take in this section is to exploit cross-sectional variation between US states, similar to Carlino and DeFina (1998, 1999). We estimate the effects of an interest rate change for every state and then regress this on the top 1% wealth share by state which we constructed above. To that end, for each state s, we first estimate the IRF of a measure of economic activity to a change in the interest rate by the Fed. Similarly to the previous section we estimate IV local projections for horizons $h \in [0, 1, \dots, H]$, but this time for each US state s:

$$y^s_{t+h} = \alpha^s_h + \beta^s_h \cdot i_t + \sum_{p=1}^{P} \Gamma^s_{h,p} \cdot X^s_{t-p} + u^s_{t+h} \tag{2.2}$$

The only difference to Section 2 is that we do not include interaction effects in the regression and that the outcome variable is specific to the state s. The remaining control variables, the deterministic elements, as well as the number of included lags ($P = 2$) remain the same. Hence, X^s_t includes y^s_t, the aggregate unemployment rate, the federal funds rate, and the log of the two aggregate price indices.[10] As before, we instrument the federal funds rate i_t with the Romer & Romer shock series.

As a proxy for economic activity, we use two different outcome variables y^s_t at the state level, the log of real state personal income (as in Carlino and DeFina 1998, 1999) and the state-level unemployment rate.[11] For the IRF of unemployment we use monthly data and consider a horizon of $H = 36$ months as in the previous section. Since state personal income is only observed quarterly, we estimate its IRF from quarterly data for horizons up to $H = 12$ quarters. We measure the impact of interest rate changes on economic activity as the average of the IRF over the first three years after the change in the interest rate, i.e., we compute the cumulative response and then divide by $H + 1$. In the following, we refer to this statistic as "impact measure".

For our baseline analysis, we restrict our sample to start in 1984q1. We choose this starting point for two reasons. First, as highlighted by Coibion (2012) and as explained in Section 2, the Federal Reserve targeted non-borrowed reserves instead of the federal funds rate in the early 1980s, which introduces some noise into the estimation of IRFs to changes in the interest rate. Owyang and Wall (2009) furthermore find that the regional effects of monetary policy in the US in the Volcker-Greenspan era post 1983 differed significantly from its effects in earlier episodes. Second, the IRS consistently published estimates on the top wealth holders on a triennial basis only from 1986 onward. We could use a longer sample to estimate the impulse responses, 1969q1 to 2007q4 for state personal income and 1976m1 to 2007m12 for state unemployment, as observations on unemployment in the states are not available for earlier periods. But in this case, we would use data from a long period, 1969 or 1976 to 1985, for estimating the state-level IRFs during which we observe wealth inequality only twice. When starting in 1984, we instead observe inequality at a constant frequency of three years. As a robustness check,

---

[10] Including the logged sum of all remaining states' personal income as an additional control barely changes the results.

[11] We obtain all these series from FRED.

we also estimate IRFs using all available data. We get similar results, which we discuss at the end of this section.

We regress our impact measure of monetary policy on the average top 1% wealth share in the sample period. In these regressions we can control for other variables that might affect the responses of economic activity to monetary policy and that could be correlated with wealth inequality. In particular, Carlino and DeFina (1998, 1999) find that a high share of income earned in the manufacturing sector of a state leads to larger responses to monetary policy shocks. They hypothesize that manufacturing is an interest-sensitive sector as purchases of housing, cars and other durable manufactured goods are relatively responsive to changes in the interest rate. Furthermore, in a subset of their regressions they find that the higher the percentage of small firms in a state the stronger the effects of monetary policy. Their proposed explanation is that small firms are more reliant on funding through banks and therefore more exposed to changes in the interest rate than large firms. Lastly, Leahy and Thapar (2019) find that US states with a high share of middle-aged people in the population react more strongly to monetary policy. The explanation they offer is that medium-aged people are relatively likely to be entrepreneurs and that therefore private firm investment becomes more responsive in states where the share of this demographic group is large.

We control for these effects by including the share of state income that is earned in the manufacturing industries, the share of employees who work in firms with less than 250 workers, the share of the population aged 35–65, and the share older than 65 years in a subset of our regressions. For the manufacturing share we divide earnings in the manufacturing industries by total earnings in a state, both provided by the Bureau of Economic Analysis at quarterly frequency. Employment shares are computed on the basis of the Business Dynamics Statistics provided by the U.S. Census Bureau on an annual basis from 1977 onward. Demographic groups are computed using annual data from the U.S. Census Bureau. For all variables we take the average over the sample period. Table 2.1 displays summary statistics of the variables we use.

3.3 Results

The first four columns of Table 2.2 show the results from regressions of the average IRF of state personal income on the average top 1% wealth share. In the first column we only use wealth inequality as an explanatory variable and then add explanatory variables in columns 2 to 4. In line with the results in the previous section a negative relationship between the average response and wealth inequality emerges. The point estimate in column 1 indicates that an increase in the top 1% wealth share by one standard deviation (5 percentage points) exacerbates the contraction of real state personal income by $0.05 \cdot 1.3 = 0.065$ percentage points on average over a horizon of three years. Figure 2.8 shows the corresponding scatter plot of the states' average top 1% shares and their cumulative

Table 2.1: Summary statistics for variables on the US state level, 1984q1 to 2007q4.

	Mean	S.d.	Min	Max
Avgerage response personal income (in %)	-0.16	0.20	-0.56	0.21
Avgerage response unemployment (in pp.)	0.08	0.08	-0.08	0.28
Top 1% wealth share	0.25	0.05	0.13	0.36
Manufacturing share	0.16	0.06	0.03	0.30
Share small firms	0.49	0.06	0.41	0.67
Share middle-aged	0.51	0.02	0.46	0.56
Share old	0.17	0.03	0.07	0.24
Observations	50			

Notes: S.d. stands for standard deviation.

IRFs. In line with Carlino and DeFina (1998, 1999) we find a negative effect of a high manufacturing share, while in contrast to them, we find that a high share of employment in small firms mutes the output response. A large fraction of middle-aged (and to a lesser extent of old-aged) leads to stronger responses to interest rate changes, as in Leahy and Thapar (2019).

Columns 5 to 8 of Table 2.2 show the results when repeating the analysis for the unemployment rate. In line with our previous findings, we estimate a positive coefficient on the top 1% wealth share, implying a stronger rise in unemployment in states where wealth is distributed more unequally. Column 5 implies that the average rise in unemployment becomes $0.05 \cdot 0.5 = 0.025$ percentage points larger when a state's top 1% wealth share increases by one standard deviation. For comparison, both the mean and the standard deviation of the average unemployment response amount to 0.08 percentage points (see Table 2.1).

3.4 Robustness

First, we use the longest possible sample periods for estimating the impulse response, from 1969q1 to 2007q4 for state personal income and from 1976m1 to 2007m12 for the unemployment rate. Table 2.A4 in the appendix shows the results. While the point estimates of the coefficient on the top 1% wealth share all have the expected sign, they are somewhat smaller and are statistically significant only in some cases. One possible explanation for this is that time-varying inequality on the state level confounds the results. As was the case for the US as a whole, wealth inequality for each state is not constant but varies over time. Since we have few observations of wealth inequality before 1984, taking the average over all observations does not assign the adequate weight to the time before 1984. For example, a state with high wealth inequality before 1984 and low wealth inequality after 1984 would be assigned a lower level of average wealth inequality than a state with low wealth inequality before 1984 and high wealth inequality after 1984. This

Table 2.2: Regression results for the cross-section of US states.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	Log state personal income				State unemployment rate			
Top 1% share	-1.3***	-1.4***	-1.3***	-1.1**	0.5**	0.6***	0.5*	0.4*
	(0.4)	(0.4)	(0.5)	(0.5)	(0.2)	(0.2)	(0.3)	(0.2)
Manuf. share		-1.1***	-1.1**	-0.7		0.4*	0.3	0.2
		(0.4)	(0.5)	(0.5)		(0.2)	(0.2)	(0.2)
Share small firms			0.2	0.9*			-0.2	-0.4*
			(0.5)	(0.5)			(0.3)	(0.2)
Share mid-aged				-6.0***				2.1***
				(1.4)				(0.7)
Share old				-1.8**				0.3
				(0.9)				(0.4)
Observations	50	50	50	50	50	50	50	50

Notes: Dependent variables are the average IRF of log real state personal income (columns 1–4) and the state unemployment rate (columns 5–8) to a 25 bp increase in the federal funds rate over a horizon of three years. Sample period is 1984q1–2007q4. Robust standard errors are reported in parentheses. A * indicates $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

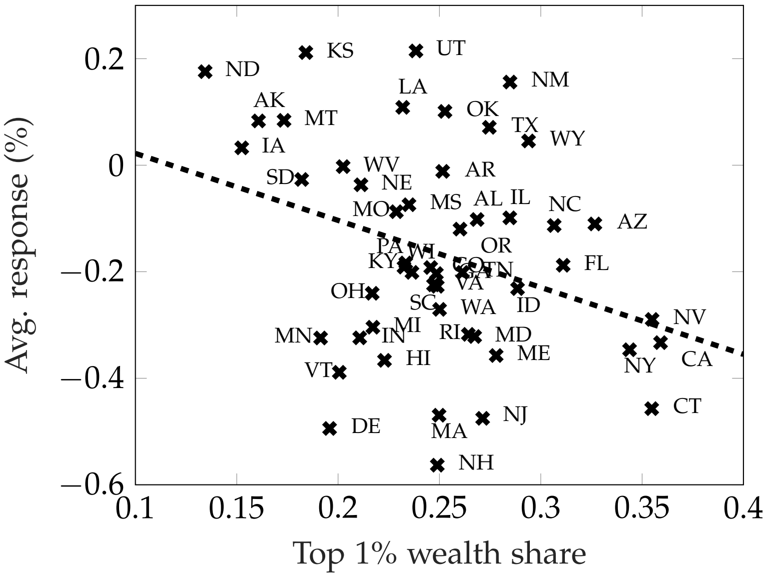


Figure 2.8: Top 1% wealth shares and average IRFs of personal income in US states.
Notes: Sample period is 1984q1–2007q4. Top 1% shares are the average over the sample period. Average IRFs are taken over the first three years after the shock.

could bias our results.

Second, we use the State Coincident Index constructed by the Federal Reserve Bank of Philadelphia as our measure of activity on the state level instead of state personal income or unemployment. The Coincident Index is available at monthly frequency from 1979m1 onward and is computed on the basis of four variables, non-farm payroll employment, average hours worked in manufacturing by production workers, the unemployment rate, and CPI-deflated wage and salary payments. The results, using the average IRF over the first $H = 36$ months after the shock as the impact measure, are shown in Table 2.A5 in the appendix. They are very similar to those obtained when using state personal income as the measure of activity (Table 2.2).

Third, we measure the impact of monetary policy at the state level not by the average but by the peak response of state personal income. Table 2.A6 in the appendix shows the results. Again, we find that responses are more pronounced in states with high inequality.

Lastly, we exploit the length of the time series and construct a two-period panel of state-level observations. We split the full sample into two subsamples of equal length, 1969q1–1988q2 and 1988q3–2007q4, and for every state estimate both the average top 1% wealth share and IRFs to monetary policy shocks separately for the two subsamples. We use the resulting panel of the average top 1% wealth share and the impact measure of monetary policy to estimate a model with state fixed effects. This allows us to control for all time-invariant characteristics of a state that might affect its response to interest rate changes. Table 2.A7 in the appendix displays the resulting estimates when using the average IRF of state personal income as our impact measure. Even when controlling for state fixed effects a negative point estimate on the top 1% share emerges, though it is not statistically significant (columns 3–6). The first two columns also display the estimated coefficient of the top 1% share for each of the two subsamples. Both are negative and statistically significant. This finding is not surprising for the second subsample (1988–2007) as it almost coincides with the subsample used in our baseline specification, 1984 to 2007. However, this finding also indicates a dependence of monetary policy transmission on wealth inequality in US states before 1988.

4 Cross-Sectional Evidence from the Euro Area

Next, we analyze the correlation between wealth inequality and the real effects of monetary policy in the cross-section of Euro Area countries. Our empirical approach is similar to the one for US states in Section 3 and to the analysis in Almgren et al. (forthcoming). The additional advantage of using Euro Area data compared to the US state-level analysis is the availability of a microdata set, the HFCS, that has detailed information on households' asset holdings and is representative at the country level. Hence, we can control for a host of potential confounding factors that may be correlated with wealth inequality, such as the share of hand-to-mouth households and the rate of homeownership.

4.1 The effects of monetary policy

We first estimate the real effects of monetary policy for all nineteen Euro Area countries using IV local projections as before. We use monthly Eurostat data from 1999m1, when the Euro was introduced, to 2020m1. For every country c and horizon $h \in [0, 1, \dots, H]$, we estimate

$$y^c_{t+h} = \alpha^c_h + \beta^c_h \cdot i_t + \sum_{p=1}^{P} \Gamma^c_{h,p} \cdot X^c_{t-p} + u^c_{t+h} \,. \tag{2.3}$$

As before, y^c_{t+h} is the outcome variable of interest in country c at time $t+h$, i_t is the nominal interest rate and X^c_t is a vector of controls. It contains country c's unemployment rate, the log of its GDP, the log of its CPI, the identified monetary policy shocks described below, and the nominal interest rate for which we take the Euro Overnight Index Average (EONIA) rate. As Almgren et al. (forthcoming), we include the shocks as controls to address the potential problem of serial correlation in the series of shocks. As before, we estimate IRFs up to a horizon of $H = 36$. Following Almgren et al. (forthcoming), we choose a lag length of $P = 3$ and include a country- and horizon-specific constant, α^c_h. We estimate the local projections at a monthly frequency. However, GDP for the Euro Area countries is only available at a quarterly frequency. To obtain a monthly series, we follow Almgren et al. (forthcoming) and employ the Chow and Lin (1971) procedure using data on unemployment, industrial production and retail trade to interpolate quarterly GDP.

We instrument the nominal interest rate using shocks identified from high-frequency movements in Overnight Indexed Swaps (OIS). In particular, we construct a monthly shock series from changes in the 3-months OIS rates around ECB monetary policy announcements, which are provided by Altavilla et al. (2019). Since ECB monetary policy decision are announced at 13:45 followed by a press conference that ends at 15:30, Altavilla et al. (2019) compute the difference in the median price of the OIS in the time between 15:40 to 15:50 and the median price between 13:25 to 13:35. Under the identifying assumption that policy decisions are the only relevant factor driving interest rates in this short time window, these changes constitute exogenous variations in nominal interest rates and are therefore valid instruments.

Using this procedure, Altavilla et al. (2019) construct a daily series of monetary policy shocks that we aggregate to monthly frequency. To do this, we follow the procedure employed in Ottonello and Winberry (2020) and Meier and Reinelt (2020) which accounts for the fact that for a shock that takes place late in a month, little time is left to affect the economy. For example, a shock on the last day of a month is much closer in time to a shock that takes place on the first day of the next month than it is to a shock on the first day of the same month, and we would expect to see this reflected in how the economy responds to the shock. To take this into account, we attribute each shock in part to the next month depending on how many days are left in the month after the day of the shock. In particular, the value of the series in month t, denoted ϵ_t, is constructed according to

$$\epsilon_t = \sum_{\tau \in D(t)} \phi(\tau, t)\tilde{\epsilon}_\tau + \sum_{\tau \in D(t-1)} (1 - \phi(\tau, t-1))\tilde{\epsilon}_\tau,$$

where $\tilde{\epsilon}_\tau$ is the value of the daily series on day τ, $D(t)$ is the set of days in month t and $\phi(\tau, t)$ is the share of days of the month after day τ. In words, a shock that occurs on the first day of a month is fully attributed to that month, whereas for a shock that occurs in the middle of the month, half is attributed to the current month and half to the next month.

Not all current Euro Area countries have been members of the Euro Area since its inception in 1999 such that some were not directly subject to ECB monetary policy in the earlier years of our sample.[12] Nevertheless, for our baseline specification we estimate impulse responses to ECB interest rate changes for all countries based on the whole time period. We think this approach is reasonable because even those countries who joined later had already pegged their exchange rates to the Euro much earlier and were thus strongly affected by the ECB's monetary policy. As a robustness check, we also estimate IRFs only based on those time periods in which a country was a member of the Euro Area. We also consider only the sub-sample of the original eleven Euro Area countries (EA11).

We first estimate (2.3) for the Euro Area as a whole. Figure 2.9 shows the estimated IRFs to a 25 basis points change in the nominal interest rate. In response to the interest rate hike, both GDP and unemployment respond as expected. GDP falls, reaching a trough at about -1.5% after one year. Unemployment responds more slowly initially but then peaks at about 0.3 percentage points. The response of GDP is larger than that of industrial production we estimated for the US (Figure 2.2, black dashed line) but it is similar to the results in Almgren et al. (forthcoming).[13]

4.2 A measure of wealth inequality at the country level

We next turn to the measurement of wealth inequality at the country level. We estimate the top 10% wealth share country by country from the HFCS. The HFCS is a survey of household finances in EU countries similar to the Survey of Consumer Finances in the US. It has been conducted in three waves between 2010 and 2017 by the individual mem-

---

[12] Slovenia joined in 2007, Cyprus and Malta in 2008, Slovakia in 2009, Estonia in 2011, Latvia in 2014 and Lithuania in 2015.

[13] Almgren et al. (forthcoming) display IRFs of GDP to an interest rate reduction by one standard deviation of the shock series. The standard deviation of our constructed shock series is 3 basis points, or 0.0003.

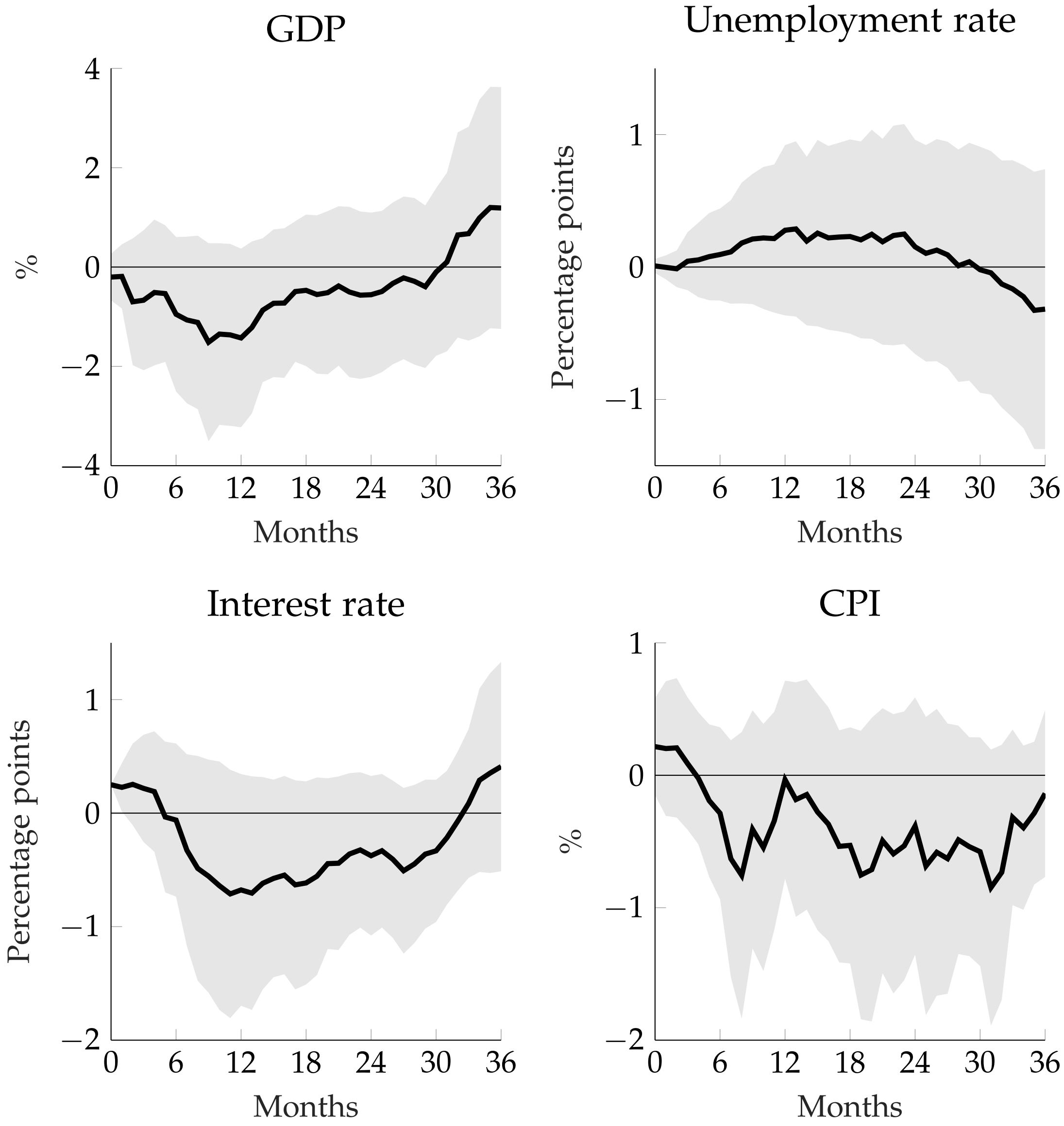


Figure 2.9: IRFs to a 25 bp increase in the nominal rate for the Euro Area as a whole.
Notes: Shaded areas indicate 90% confidence intervals based on Newey and West (1987) standard errors.

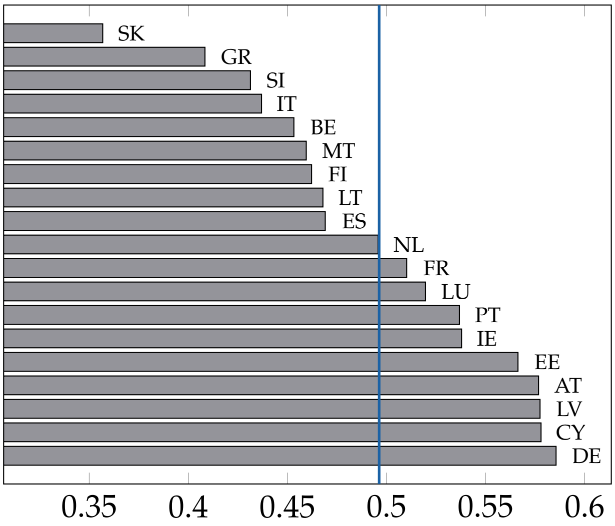


Figure 2.10: Top 10% wealth share in Euro Area countries.
Notes: Top 10% wealth shares, averaged across all waves of the HFCS for which data on net worth exists in a given country. Solid line: Average across countries.

ber states and is representative on the national level. Importantly, the core questions of the survey used for our analysis are identical across countries which allows for an easy comparison between countries. To obtain an estimate of the top 10% wealth share for every country, we define net worth for every household as the difference between total assets excluding public and occupational pensions plans and total outstanding household liabilities.[14] Total assets are the sum of total real assets, which consist of real estate, vehicles, self-employed businesses, and other valuables, and total financial assets, consisting of deposits, mutual funds, bonds, non-self-employed businesses, shares, managed accounts, money owed to the household, life-insurance and other pensions, and other assets. Total liabilities consist of mortgage debt and other debt such as credit card debt and consumer loans.[15]

We compute the top 10% wealth share based on this definition of wealth for every country and each HFCS wave and then average over the three HFCS waves to obtain a single measure of wealth inequality for every country. Figure 2.10 depicts the resulting measure. In the average Euro Area country, the richest ten percent of households hold about 50% of total net worth as indicated by the vertical line. However, there is large variation across countries. The top 10% wealth share is largest in Germany with an average of 59% between 2010 and 2017. It is lowest in Slovakia and Greece at 36% and 41% respectively.

---

[14] For the construction of our measure of wealth inequality, as well as for all other variables we use in our analysis below that are derived from the HFCS, we only consider households whose head is aged 20–75.

[15] This definition corresponds to variable DN3001 (Net wealth excluding public and occupational pensions) in the HFCS.

Table 2.3: Summary statistics for Euro Area countries, 1999m1 to 2020m1.

	Mean	S.d.	Min	Max
Average response GDP (in %)	-0.47	0.86	-2.26	1.37
Average response unemployment (in pp.)	0.05	0.45	-0.85	0.93
Top 10% wealth share	0.50	0.07	0.36	0.59
Observations	19			

Notes: S.d. stands for standard deviation.

Table 2.4: Regression of average responses to monetary policy shocks on wealth inequality.

	(1) GDP	(2) U	(3) U EA11	(4) U in EA	(5) U peak	(6) GDP	(7) U
Top 10% share	-4.6^{*}	4.1^{***}	3.7	4.9^{**}	4.7^{**}		
	(2.5)	(1.0)	(2.1)	(2.0)	(1.8)		
Top 1% share						-6.1	3.9^{**}
						(3.7)	(1.6)
Observations	19	19	11	19	19	19	19

Notes: Dependent variable is the average IRF of GDP (in %) or unemployment ("U", in p.p.) to a 25 bp increase of the interest rate over a horizon of three years. Column 3: sample restricted to original 11 Euro Area countries. Column 4: sample restricted to countries in the Euro Area at a given point in time. Column 5: peak response of unemployment. Robust standard errors are reported in parentheses. A * indicates $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

4.3 Results

Table 2.3 reports summary statistics for both the average GDP and unemployment responses to a 25 bp monetary policy shock as well as the top 10% wealth shares for all 19 Euro Area countries. The means of the average GDP and unemployment responses are in line with the IRFs for the Euro Area as a whole (Figure 2.9). Compared to the US states, the responses in the Euro Area countries display a much higher standard deviation. This might owe in part to the much shorter sample period over which we estimate the IRFs.

The first column in Table 2.4 shows the result of a linear regression of the average GDP response on the top 10% wealth share. As for the US states, we estimate a negative relationship between inequality and the output response to an increase in the interest rate. The point estimate indicates that an increase in the top 10% wealth share by one standard deviation is associated with a $0.07 \cdot 4.6 = 0.32$ percentage points stronger contraction in GDP in response to a 25 basis points shock.

In the second column we repeat the analysis, this time using the average response of unemployment as the impact measure. The estimated effect is positive and statistically significant at the 1% level. The point estimate implies that an increase in the top 10%

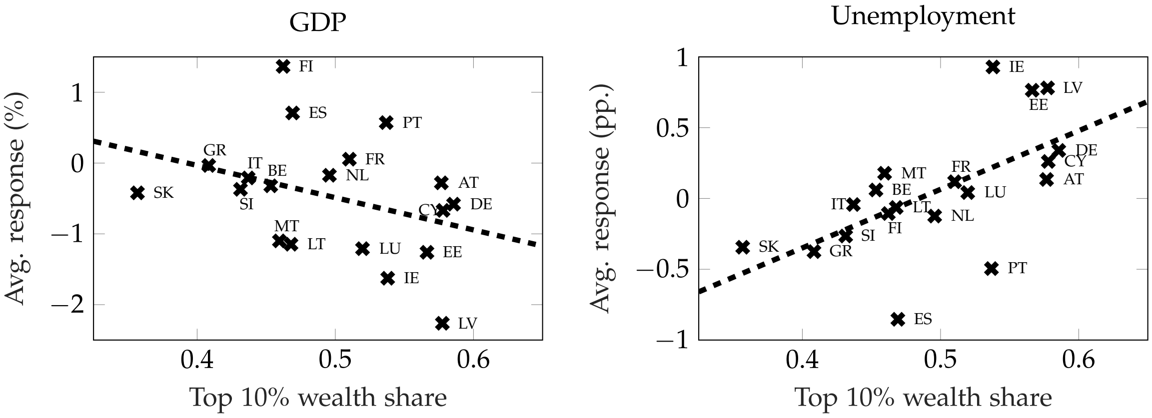


Figure 2.11: Top 10% wealth share and average response of GDP (left) and unemployment (right) in Euro Area countries.

wealth share by one standard deviation is associated with an increase in the unemployment response to a 25 basis points rate hike by $0.07 \cdot 4.1 = 0.29$ percentage points. Given that the standard deviation of the average unemployment responses across countries is 0.45 percentage points, this is a substantial effect. We return to a discussion of the remaining columns of Table 2.4 below. Figure 2.11 shows the correlation between the degree of wealth inequality in Euro Area countries and their average response of GDP (left panel) and unemployment (right panel).

Additional controls There are several alternative explanations for the observed differences in the response to policy rate changes, and the availability of comparable country-level data in the Euro Area allows us to investigate some of them by including additional controls.[16] Since our sample is substantially smaller than on the US state level, we only include one control at a time.

First, we add the share of hand-to-mouth households as control, i.e., households who hold only very few liquid assets. Kaplan et al. (2018) argue that a higher share of liquidity constrained households raises the aggregate marginal propensity to consume and thereby strengthens the indirect effects of monetary policy. The first two columns in Table 2.5 confirm the findings in Almgren et al. (forthcoming): both GDP and the unemployment rate respond more strongly to interest rate changes in countries with a higher share of hand-to-mouth households. However, the estimated coefficients on wealth inequality do not change much relative to the baseline when we control for the hand-to-mouth share, and they remain statistically significant.

Second, labor market institutions may be important for the response to monetary policy, especially when we use the unemployment rate as a proxy for economic activity. Therefore, we add an index measuring strictness of employment protection constructed

---

[16] We obtain from Eurostat data on household debt to GDP, the share of hours worked in the manufacturing sector, of employees in small firms, and of middle-aged households. We construct the remaining controls from the HFCS, unless stated otherwise.

Table 2.5: Regressions of impact measures on wealth inequality and controls.

	(1) GDP	(2) U	(3) GDP	(4) U	(5) GDP	(6) U	(7) GDP	(8) U	(9) GDP	(10) U
Top 10% share	-4.1*	4.0***	-5.4	4.3***	-7.1**	4.4***	-3.6	4.2***	-6.9**	5.0***
	(2.0)	(0.9)	(3.4)	(1.2)	(3.0)	(1.3)	(2.1)	(1.0)	(2.5)	(1.0)
Htm share	-3.0**	0.8*								
	(1.3)	(0.5)								
Emp. protect.			0.3	-0.3**						
			(0.3)	(0.1)						
Home own.					-3.0**	0.3				
					(1.3)	(0.7)				
Adj. mortg.							-0.7	-0.1		
							(0.6)	(0.3)		
Debt/GDP									1.6**	-0.6*
									(0.7)	(0.3)
Observations	19	19	16	16	19	19	18	18	19	19

Notes: Dependent variable is the average IRF of GDP (columns with "GDP") or unemployment ("U") to a 25 bp increase of the interest rate over a horizon of three years. Robust standard errors are reported in parentheses. A * indicates $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.6: Regressions of impact measures on wealth inequality and controls, continued.

	(1) GDP	(2) U	(3) GDP	(4) U	(5) GDP	(6) U	(7) GDP	(8) U
Top 10% share	-4.7*	4.3***	-4.6	4.1***	-6.0**	4.1***	-5.1**	4.2***
	(2.6)	(1.1)	(2.7)	(1.1)	(2.5)	(1.1)	(2.1)	(1.1)
Manuf. share	-1.6	1.8						
	(2.8)	(1.4)						
Share small firms			-3.1	0.2				
			(2.2)	(0.8)				
Share mid-aged					-10.2**	-0.5		
					(4.6)	(2.0)		
Stock market part.							4.1**	-0.3
							(1.7)	(0.6)
Observations	19	19	19	19	19	19	19	19

Notes: Dependent variable is the average IRF of GDP (columns with "GDP") or unemployment ("U") to a 25 bp increase of the interest rate over a horizon of three years. Robust standard errors are reported in parentheses. A * indicates $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

by the OECD (2020) as an additional control.[17] The index measures the strictness of regulation on collective dismissals, and high values indicate a stronger protection of the workforce. As shown in columns 3 and 4 we only find a statistically significant (dampening) effect on the unemployment response and adding the index as a control does not change the conclusion about the role of wealth inequality.

Beraja et al. (2019) and Wong (2021) suggest that the rate of homeownership and the share of adjustable-rate mortgages is important for the transmission of monetary policy. Homeowners are likely to have mortgages and are therefore particularly affected by interest rate changes. This effect could be even stronger if many mortgages have adjustable rates since monetary policy has a direct effect on existing mortgages in this case. Thus, we control for the homeownership rate and the share of households with adjustable-rate mortgages in columns 5 to 8.[18] The results we obtain are mixed. If anything, a higher share of homeowners leads to stronger effects of monetary policy as expected, but we do not find a significant role for the share of adjustable-rate mortgages.

For the US, Alpanda and Zubairy (2019) find evidence that higher levels of household debt are associated with smaller effects of monetary policy shocks. Columns 9 and 10 show that this relationship also holds in the cross-section of Euro Area countries. The point estimates for the effect of wealth inequality become even larger when controlling for household debt.

Next, as described in the previous section, regions with a large manufacturing industry might respond more strongly to monetary policy. We do not find a statistically significant effect of the share of total hours worked in the manufacturing sector, though the point estimates have the expected sign (Table 2.6, columns 1 and 2). In contrast to the results on the US state level, we find that a large share of employment in small firms is associated with larger effects of monetary policy, though the relationship is not statistically significant (columns 3 and 4).

As explained before, Leahy and Thapar (2019) find demographics to be important for the transmission of monetary policy in the US, so we control for the share of the population aged 35–65 in columns 5 and 6. We find a statistically significant amplifying effect of the share of middle-aged households on the response of GDP also in the Euro Area, but there is no significant effect on the unemployment response. Lastly, we control for stock market participation, measured as the share of households that either hold stocks directly or via mutual funds. Contrary to the results in Melcangi and Sterk (2020), we find that, if anything, higher stock market participation weakens the effects of monetary policy on real activity.

In sum, many of the factors that were found to affect the strength of the monetary transmission mechanism turn out to be important also in our data. Wealth inequality, however, appears to influence monetary policy transmission beyond its working through

---

[17] The index is not available for Cyprus, Lithuania, and Malta.

[18] Data on mortgage types are not available for Finland.

either of these factors.

4.4 Robustness

We conduct a number of robustness checks shown in columns 3 to 7 of Table 2.4. First, in column 3 we restrict the sample to the original eleven member states. We estimate a similar effect on the unemployment response as in the baseline but since the sample only consists of eleven countries in this case, it is not statistically significant. The fourth column corresponds to the case where we estimate responses to monetary policy using only those country-month observations where a given country was a member of the Euro Area. In this case we find an even stronger effect of wealth inequality on the effectiveness of monetary policy, but the estimate also has a larger standard error.

Next, in column 5 we look at the peak response of unemployment instead of its average response. The point estimate in this case is similar to the estimate for the average response. Lastly, we regress our impact measures on the top 1% wealth share instead of the top 10% share (columns 6 and 7). We find that a higher top 1% share is associated with stronger responses of GDP, but not of unemployment. However, the standard errors are larger than when considering the top 10% share such that only the effect on the unemployment response is statistically significant.

5 Conclusion

This paper was motivated by two strands of literature that have received a lot of attention over the past decade. The first one documents significant variation across countries and time in the degree of wealth inequality in the population. The second emphasizes the role of household heterogeneity for short-run phenomena such as the transmission of monetary policy. We studied empirically how the strength of monetary policy transmission depends on the degree of wealth inequality, and we found that the effects of interest rate changes are state-dependent. More unequal distributions of household wealth are associated with stronger effects of monetary policy on real variables, such as GDP, industrial production and unemployment. This relationship holds in all three contexts we considered, on the aggregate level in the US and the UK, in the cross-section of US states and in the cross-section of Euro Area countries.

Our empirical analysis implies that the distribution of wealth matters for monetary transmission. This provides an argument for using Heterogeneous Agent New Keynesian (HANK) models to analyze monetary policy. Our study can help guide the development of such models. Analyzing further which underlying forces are responsible for our empirical results and designing corresponding HANK models appear like interesting avenues for future research.

Policymakers in central banks take an increasing interest in the interaction of monetary policy and household heterogeneity (BIS 2021; Dossche et al. 2021). As mentioned in the beginning, our findings are relevant for their current discussions. Based on our results, the negative output and employment effects of raising interest rates are larger today when wealth inequality is at historically high levels than they were on average in the past.

Appendix

A.1 Aggregate time series: identifying assumptions

We are interested in the causal effect of an interest rate change on the outcome variable of interest, y_{t+h} for a given level of inequality. According to equation (2.1), it is given by

$$\frac{\mathrm{d}y_{t+h}}{\mathrm{d}i_t} = \beta_h + \beta_h^+ ineq_t. \tag{2.4}$$

Hence, we need consistent estimates of β_h and β_h^+. Denoting the Romer & Romer shock at time t by RR_t. Here and in the following we understand all variables as the residuals from a linear projection on the control variables. For the estimates of β_h to be consistent, we require that our instrument $(RR_t, ineq_t RR_t)$ is exogenous, i.e., uncorrelated with the error term. This is the case if

$$Cov(RR_t, u_{t+h}) = 0 \quad \text{and} \quad Cov(ineq_t RR_t, u_{t+h}) = 0.$$

We assume $\mathbb{E}[RR_t|u_{t+h}] = \mathbb{E}[RR_t]$. Since $\mathbb{E}[u_t] = 0$, we obtain

$$Cov(RR_t, u_t) = 0.$$

The assumption that contemporaneous and future structural shocks, which constitute u_{t+h}, do not contain information about the Romer & Romer shocks, i.e., $\mathbb{E}[RR_t|u_{t+h}] = \mathbb{E}[RR_t]$, follows from the identification strategy of Romer and Romer (2004) and the definition of structural shocks.

The second exogeneity condition $Cov(RR_t \cdot \text{ineq}_t, u_{t+h}) = 0$ holds if

$$\mathbb{E}[RR_t \cdot \text{ineq}_t \cdot u_{t+h}] = 0.$$

This is fulfilled if $\mathbb{E}[\text{ineq}_t RR_t|u_{t+h}] = \mathbb{E}[\text{ineq}_t RR_t]$. Given the results in Coibion et al. (2017), however, one might suspect a contemporaneous relationship between structural shocks contained in u_{t+h} and wealth inequality. Therefore, we lag inequality by one year (twelve months) when using it as an instrument and assume $\mathbb{E}[\text{ineq}_{t-12} RR_t|u_{t+h}] = \mathbb{E}[\text{ineq}_{t-12} RR_t]$. Since past inequality cannot react to contemporaneous shocks the only assumption we make is therefore that the Romer & Romer shocks are truly exogenous, and do not contain a systematic response of the FOMC to contemporaneous shocks.

Discussion of identification following Stock and Watson (2018) We now formalize the argument above using the framework and notation in Stock and Watson (2018). Let $Y_t = (Y_{1,t}, Y_{2,t}, \dots)'$ denote the vector of endogenous variables, e.g., interest rate, output, inflation, $\dots$, and let $\varepsilon_t = (\varepsilon_{1,t}, \varepsilon_{2,t}, \dots)$ denote the vector of structural shocks to the endogenous variables. We assume

$$Y_t = B(L)\varepsilon_t + B^+(L) ineq_t \varepsilon_t, \tag{2.5}$$

where $B(L) = \beta_0 + \beta_1 L + \beta_2 L^2 \dots$ and β_h is a matrix with coefficients $\beta_{h,mn}$ and $B^+(L)$ is defined analogously. We have that

$$\begin{aligned} Y_{1,t} =& \beta_{0,11}\varepsilon_{1,t} + \beta^+_{0,11} ineq_t \varepsilon_{1,t} + \{\varepsilon_{2:n,t}, \varepsilon_{t-1}, \varepsilon_{t-2}, \dots\} \\ &+ \{ineq_t \varepsilon_{2:n,t}, ineq_t \varepsilon_{t-1}, ineq_t \varepsilon_{t-2}, \dots\}, \end{aligned}$$

where the notation 2:n denotes all elements of a vector except the first and $\{\dots\}$ denotes a linear combination of the elements inside the braces. In our case $Y_{1,t}$ is the nominal interest rate. With the unit effect normalization $\beta_{0,11} = 1$ and $\beta^+_{0,11} = 0$, we have that

$$Y_{1,t} = \varepsilon_{1,t} + \{\varepsilon_{2:n,t}, \varepsilon_{t-1}, \varepsilon_{t-2}, \dots\} + \{ineq_t \varepsilon_{2:n,t}, ineq_t \varepsilon_{t-1}, ineq_t \varepsilon_{t-2}, \dots\}, \tag{2.6}$$

i.e., the structural (monetary policy) shock ε_1 moves the nominal interest rate Y_1 by one unit (percentage point). We are interested in the response of variable Y_2 to the shock ε_1 h periods ahead. According to (2.5), it is determined by $\beta_{h,21}$ and $\beta^+_{h,21}$ in

$$Y_{2,t+h} = \beta_{h,21}\varepsilon_{1,t} + \beta^+_{h,21} ineq_t \varepsilon_{1,t} + u_{2,t+h}.$$

Substituting for $\varepsilon_{1,t}$ from (2.6) gives,

$$Y_{2,t+h} = \beta_{h,21} Y_{1,t} + \beta^+_{h,21} ineq_t Y_{1,t} + \tilde{u}_{2,t+h},$$

with

$$\begin{aligned} \tilde{u}_{2,t+h} =& \{\varepsilon_{t+h}, \varepsilon_{t+h-1}, \dots, \varepsilon_{2:n,t}, \varepsilon_{t-1}, \varepsilon_{t-2}, \dots\} \\ &+ \{ineq_{t+h}\varepsilon_{t+h}, ineq_{t+h-1}\varepsilon_{t+h-1}, \dots, ineq_t \varepsilon_{2:n,t}, ineq_t \varepsilon_{t-1}, ineq_t \varepsilon_{t-2}, \dots\}. \end{aligned}$$

Hence, the instrument $Z_t = (RR_t, ineq_t RR_t)'$ would be valid if it satisfied

$$\begin{aligned} \mathbb{E}\left[(\varepsilon_{1,t}, ineq_t \varepsilon_{1,t}) Z_t\right] &\neq 0 \quad \text{relevance} \\ \mathbb{E}\left[(\varepsilon_{2:n,t}, ineq_t \varepsilon_{2:n,t}) Z_t\right] &= 0 \quad \text{contemporaneous exogeneity} \\ \mathbb{E}\left[(\varepsilon_{t+j}, ineq_{t+j} \varepsilon_{t+j}) Z_t\right] &= 0 \; \forall j \neq 0 \quad \text{lead-lad exogeneity} \end{aligned}$$

(cf. Stock and Watson 2018). As argued in Romer and Romer (2004) and in the main text, RR_t is informative about contemporaneous monetary policy shocks but independent of all other contemporaneous and all past and future shocks (at least conditional on the observables included as controls).[19] This ensures the relevance and exogeneity of RR_t. THe exogeneity of $ineq_t RR_t$ might be more problematic. In particular, other structural shocks could influence inequality contemporaneously, in which case contemporaneous exogeneity would not hold, $\mathbb{E}\left[\varepsilon_{2:n,t} ineq_t RR_t\right] \neq 0$. We therefore use lagged inequality for the instrument, $\tilde{Z}_t = (RR_t, ineq_{t-12} RR_t)'$. By definition, current shocks cannot influence inequality in the previous year, such that contemporaneous exogeneity is satisfied for $\tilde{Z}_t$. What about lead-lag exogeneity? Clearly, future shocks cannot influence inequality today, such that lead exogeneity holds. Lag exogeneity also holds, if we assume that past shocks only influence inequality through other macro variables for which we control. Due to the high persistence of inequality, instrument relevance also holds for $\tilde{Z}_t$.

---

[19] We do not make explicit here, that we include control variables such that all variables should be understood as the residual from a linear projection on the controls.

A.2 Additional aggregate results for the US

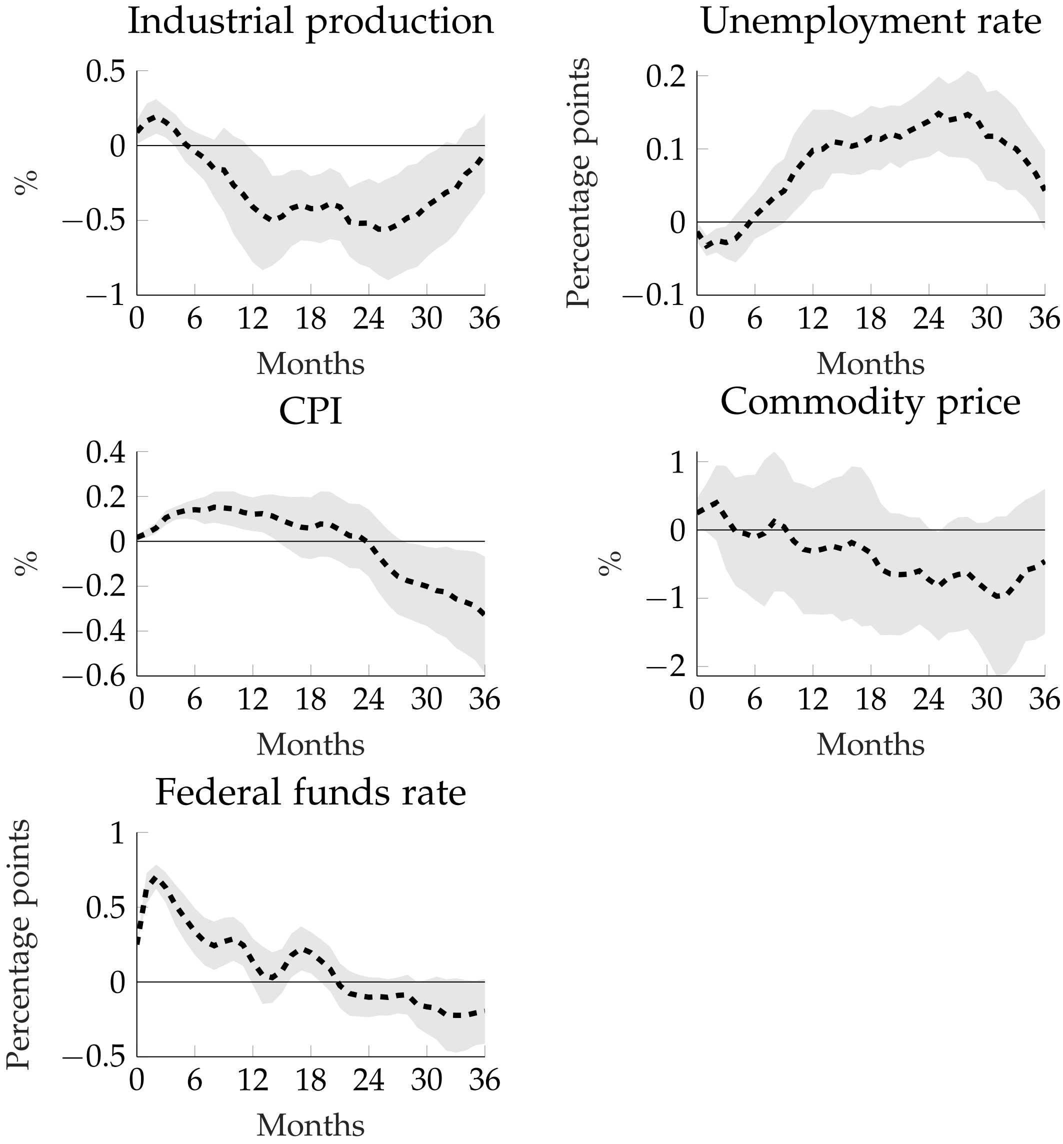
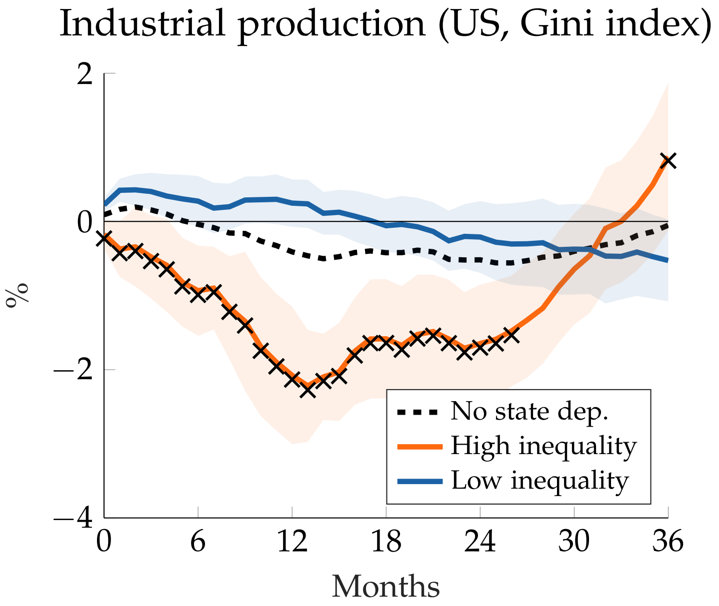


Figure 2.A1: Unconditional IRFs to 25 basis points change in federal funds rate.
Notes: Shaded areas are 90% confidence intervals based on Newey and West (1987) standard errors.



Notes: ineq_t is measured by the Gini index. Black dashed: No state dependence is imposed. Blue: Regime of low inequality (first quartile of observed inequality). Red: Regime of high inequality (third quartile). Confidence intervals are at the 90% level and based on Newey and West (1987) standard errors. Black crosses indicate horizons at which we reject equality of the IRFs at 90% confidence level ($H_0 : \beta_h^+ = 0$).

Figure 2.A2: Impulse response to 25 basis points change in federal funds rate.

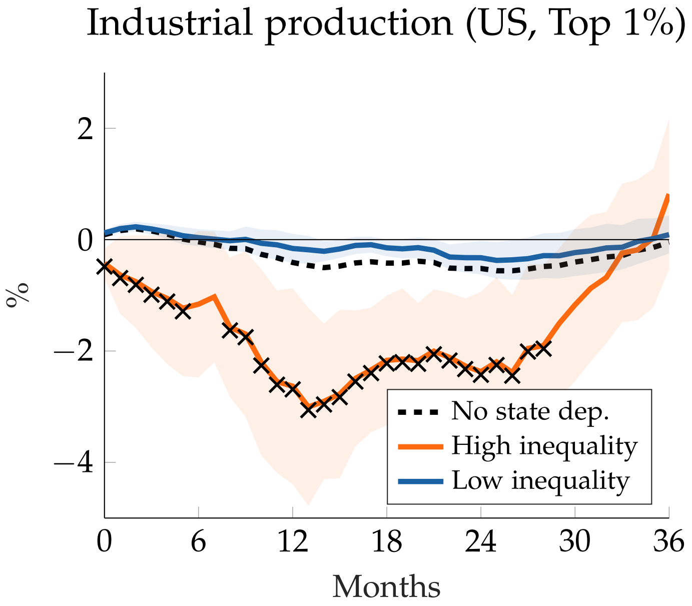


Figure 2.A3: Impulse response to 25 basis points change in federal funds rate.
Notes: ineq_t is measured by the top 1% wealth share. Black dashed: No state dependence is imposed. Blue: Regime of low inequality (first quartile of observed inequality). Red: Regime of high inequality (third quartile). Confidence intervals are at the 90% level and based on Newey and West (1987) standard errors. Black crosses indicate horizons at which we reject equality of the IRFs at 90% confidence level ($H_0 : \beta_h^+ = 0$).

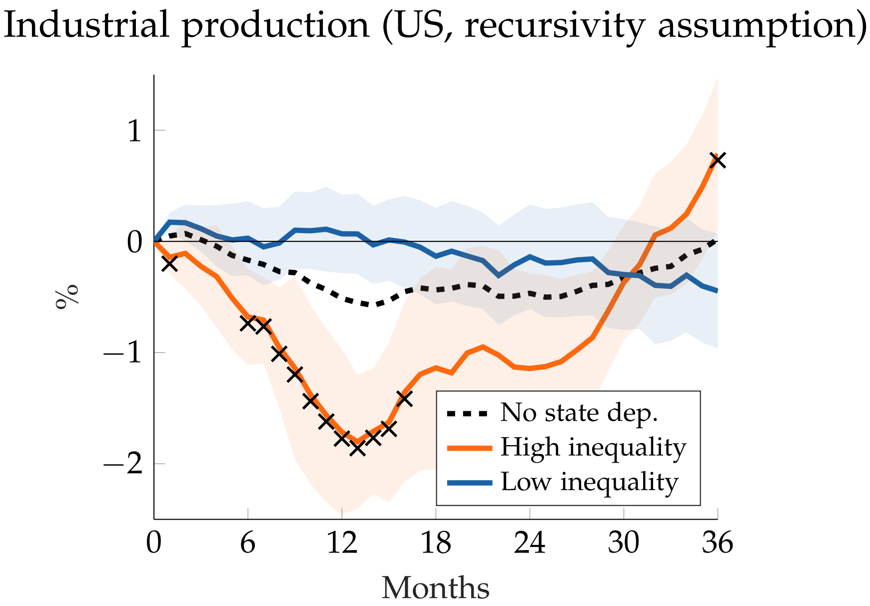


Figure 2.A4: Impulse response to 25 basis points change in federal funds rate.
Notes: Recursivity is imposed. Black dashed: No state dependence is imposed. Blue: Regime of low inequality (first quartile of observed inequality). Red: Regime of high inequality (third quartile). Confidence intervals are at the 90% level and based on Newey and West (1987) standard errors. Black crosses indicate horizons at which we reject equality of the IRFs at 90% confidence level ($H_0 : \beta_h^+ = 0$).

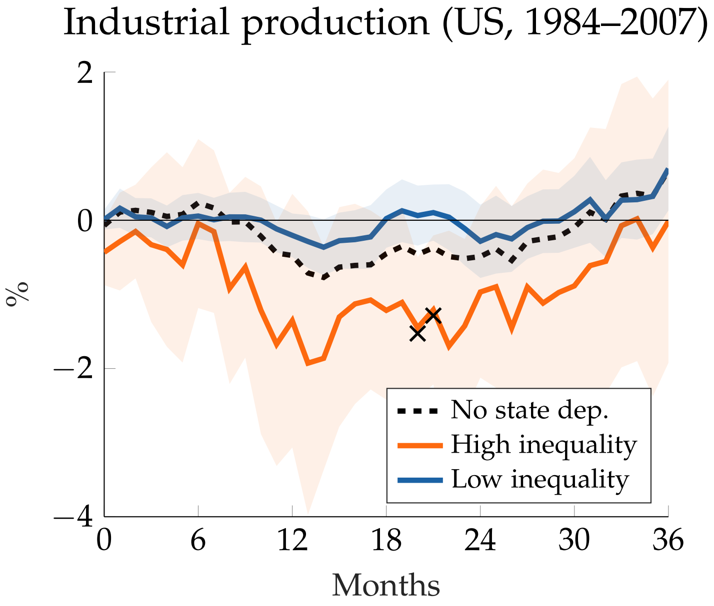


Figure 2.A5: Impulse response to 25 basis points change in federal funds rate.
Notes: Sample period: 1984m1–2007m12. Black dashed: No state dependence is imposed. Blue: Regime of low inequality (first quartile of observed inequality). Red: Regime of high inequality (third quartile). Confidence intervals are at the 90% level and based on Newey and West (1987) standard errors. Black crosses indicate horizons at which we reject equality of the IRFs at 90% confidence level ($H_0 : \beta_h^+ = 0$).

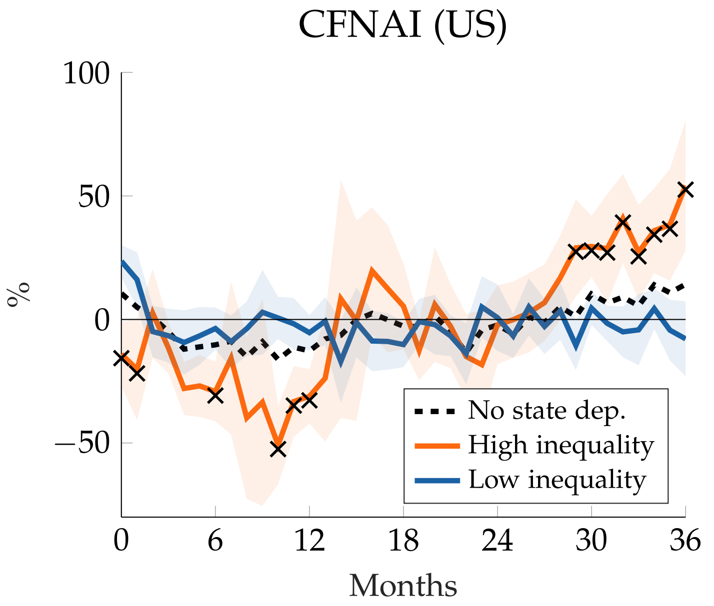


Figure 2.A6: Impulse response to 25 basis points change in federal funds rate.
Notes: Measure of output is the Chicago Fed National Activity Index. Black dashed: No state dependence is imposed. Blue: Regime of low inequality (first quartile of observed inequality). Red: Regime of high inequality (third quartile). Confidence intervals are at the 90% level and based on Newey and West (1987) standard errors. Black crosses indicate horizons at which we reject equality of the IRFs at 90% confidence level ($H_0 : \beta_h^+ = 0$).

A.3 Construction of the top 1% wealth share

For each US state, the SOI Bulletins provide estimates of two numbers that we use in our computation, the total wealth held by the top wealth holders and the number of top wealth holders. In some years, however, the data provided by the IRS is restricted to a subset of the top wealth holders that lie below or above certain cut-off levels in terms of the gross assets or net worth they possess. Table 2.A1 lists these cut-offs.

In a first step, we therefore adjust the given values for total net worth of top wealth holders and the number of top wealth holders to correspond to the given threshold levels in terms of *net worth*. For instance, in 1976 we ask what fraction of the top wealth holders' wealth is owned by the top wealth holders whose net worth exceeds $120,000. This is only a subset of the top wealth holders whose gross assets lie beyond $120,000, for which the value is known. The SOI Bulletins provide information on how much net worth is owned by top wealth holders with gross assets exceeding but net worth falling short of $120,000 on the aggregate US level. We can therefore compute the fraction f of net worth owned by these (poorest) top wealth holders. We then multiply the net worth of top wealth holders in each US state by $(1 - f)$ to arrive at the adjusted total net worth of top wealth holders. We proceed analogously for the number of top wealth holders.

For each state and each year for which the IRS provides information on top wealth holders we are now equipped with the following information:

- The (adjusted) definition of a top wealth holder: A person is a top wealth holder if

Table 2.A1: Wealth cut-offs in between which estimates of wealth holdings are available.

Year	Cut-off below ($\approx$ percentile)	Cut-off above ($\approx$ percentile)	SOI Bulletin	Author(s) of SOI Bulletin
1976	\$120,000 (6.1)	— (0)	Summer 1983	M. Schwartz
1982	\$325,000 (2.8)	— (0)	Spring 1988	M. Schwartz
1986	\$500,000 (1.6)	$\underline{\$10\text{m}}$ (0.012)	Spring 1990	M. Schwartz & B. Johnson
1989	\$600,000 (1.9)	$\underline{\$10\text{m}}$ (0.020)	Spring 1993	B. Johnson & M. Schwartz
1992	\$600,000 (2.0)	$\underline{\$10\text{m}}$ (0.020)	Winter 1998	B. Johnson
1995	\$600,000 (2.5)	$\underline{\$10\text{m}}$ (0.023)	Winter 2000	B. Johnson
1998	$\underline{\$1\text{m}}$ (1.4)	— (0)	Winter 2003	B. Johnson & L. Schreiber
2001	$\underline{\$1\text{m}}$ (1.7)	— (0)	Winter 2006	B. Johnson & B. Raub
2004	$\underline{\$1.5\text{m}}$ (1.0)	— (0)	Fall 2008	B. Raub
2007	$\underline{\$2\text{m}}$ (0.8)	— (0)	Winter 2012	B. Raub & J. Newcomb

Notes: Numbers are underlined if they correspond to net worth and not underlined if they correspond to gross assets.

her net worth lies between a and b dollars, where a and b correspond to the cut-offs shown in Table 2.A1.

- The total net worth of top wealth holders in a state: Denote this number by NW.
- The share of top wealth holders in the population: Denote this number by s.

The goal is to use this information to construct a measure of inequality that is comparable across states. We make the following assumptions.

Assumption 4. *The distribution of net worth x for some state at some time is given by the probability distribution function f. Its right tail is assumed to follow a Pareto distribution, i.e., for some $x_M < a$*

$$f(x) = \begin{cases} \phi(x) & x \leq x_M \\ g(x)\,(1-\Phi(x_M)) & x > x_M \end{cases},$$

where g is the density of the Pareto distribution with scale parameter x_M and shape parameter k and ϕ is some unknown pdf with Φ the corresponding cdf.

Denote by N the total population in a state. It follows

$$\begin{aligned} NW = N\int_a^b xf(x)\,\mathrm{d}x &= N\int_a^b xg(x)\,\mathrm{d}x\,[1-\Phi(x_M)] \\ &= Nx_M^k\frac{k}{1-k}\left(b^{1-k}-a^{1-k}\right)[1-\Phi(x_M)] \end{aligned}$$

and

$$s = \int_a^b f(x)\,\mathrm{d}x = (G(b)-G(a))\,[1-\Phi(x_M)] \tag{2.7}$$

where $G(\cdot)$ is the cdf of the Pareto distribution. The average net worth of a top wealth holder $NW/(N \cdot s)$ implicitly defines the shape parameter k of the Pareto distribution

$$\frac{NW}{N \cdot s} = \frac{\int_a^b xg(x)\,\mathrm{d}x}{G(b) - G(a)},$$

The total wealth of the top T wealth holders, for $T < 1 - \Phi(x_M)$, is given by

$$TopTPercWealth = N \int_t^{\infty} xf(x)\,\mathrm{d}x,$$

with $t = x_M(\frac{1-\Phi(x_M)}{T})^{1/k}$. This yields

$$TopTPercWealth = N\frac{k}{k-1}x_M T^{\frac{k-1}{k}} \left[1 - \Phi(x_M)\right]^{\frac{1}{k}},$$

and using (2.7)

$$TopTPerWealth = N\frac{k}{k-1}T^{\frac{k-1}{k}} s^{1/k} \left(a^{-k} - b^{-k}\right)^{-1/k}. \tag{2.8}$$

Dividing (2.8) by the state's total wealth gives the wealth share of the richest $T \cdot 100\%$. As a measure of the total population size N we use data from the U.S. Census Bureau (population aged 20 and above).

Lastly, we require a measure of total wealth on the state level, which is not readily available. We therefore use the following procedure. We obtain total US household wealth that corresponds to the items included in the net worth measures used by the IRS from Kopczuk and Saez (2004).[20] We then use data on capital income from the Bureau of Economic Analysis (item "Dividends, interest, and rent") which is available both for the US and on the state level. We then divide total US net wealth by capital income, backing out an aggregate interest rate. We use this interest rate to capitalize capital income on the state level, i.e., we multiply capital income on the state level with the aggregate interest rate. Implicitly we therefore assume that the portfolio of assets in each state earns the same interest rate in a given year.

Figure 2.A7 plots our self-constructed top 1% share for the US, as well as the estimate from Kopczuk and Saez (2004) (extended by Saez and Zucman (2016) for the years 2001 and 2004) who rely on confidential individual estate tax return data. While our measure displays a somewhat higher level as well as larger amplitude over time than theirs, overall, both the level and the dynamics of our wealth share are broadly consistent with Kopczuk and Saez (2004) and Saez and Zucman (2016).[21] Note also that for the identifi-

---

[20] Their time series on total wealth ends in 2002, and we therefore miss two observations, 2004 and 2007. Since the ratio of total US household net worth as measured by the Federal Reserve Board (series TNWBSHNO) to Kopczuk and Saez (2004)'s measure has historically been very stable (mean: 1.36, max: 1.41, min: 1.32), we divide the Fed's measure by the mean of this ratio to obtain total net worth for the two last years in our sample.

[21] The fact that estimates of top wealth shares using the estate tax multiplier method do not show as

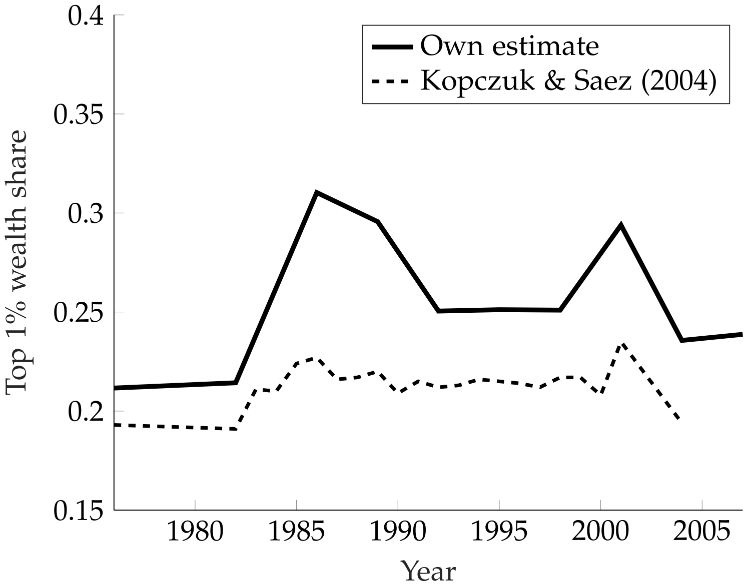


Figure 2.A7: Top 1% wealth share in the US, own estimates and estimates from Kopczuk and Saez (2004).

cation of the effects of wealth inequality on the states' responses to monetary policy in Section 3 we only require that we do not make any systematic error in measuring wealth inequality *across* US states. Over- or underestimating the top 1% share at any point in time *in all states* would not confound our results.

Figure 2.A8 shows the top 1% wealth share, averaged over time, for all US states. Nevada is the state with the highest estimated average wealth inequality (top 1% share of 35.7%), followed by California, Connecticut, and New York. Both Texas and Florida also feature above-average inequality. In the mid-western states, most notably North Dakota (top 1% share of 14.3%), Iowa, Montana, and South Dakota wealth is rather equally distributed. These patterns are broadly in line with the concentration of top wealth holders or millionaires in the population, reported graphically in several of the SOI Bulletins.

---

stark an increase in inequality since the 1980s as do estimates based on capitalizing income (Section 2) or based on the Survey of Consumer Finances is well documented. Kopczuk (2015) and Saez and Zucman (2016) discuss potential reasons for this, among others a rising mortality gradient in age over time and increasing estate tax planning.

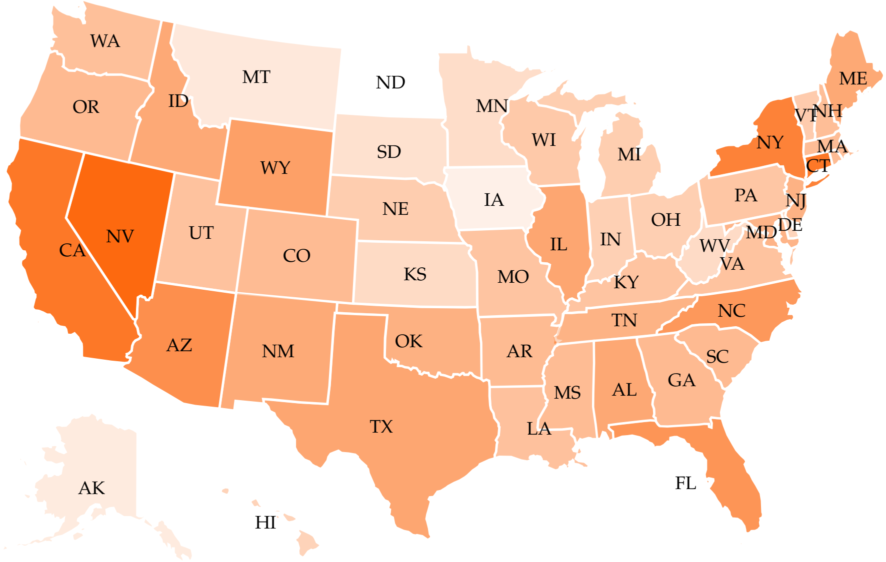


Figure 2.A8: Average top 1% wealth share in US states 1976–2007, darker = higher.

A.4 Additional state-level results

Table 2.A2: Summary statistics for variables on the US state level, 1976q1 to 2007q4.

	Mean	S.d.	Min	Max
Average response unemployment (in pp.)	0.08	0.04	0.01	0.17
Top 1% wealth share	0.24	0.04	0.14	0.36
Manufacturing share	0.18	0.07	0.04	0.32
Share small firms	0.50	0.06	0.41	0.67
Share middle-aged	0.49	0.01	0.45	0.53
Share old	0.17	0.03	0.07	0.24
Observations	50			

Notes: S.d. stands for standard deviation.

Table 2.A3: Summary statistics for variables on the US state level, 1969m1 to 2007m12.

	Mean	S.d.	Min	Max
Average response personal income (in %)	-0.12	0.08	-0.27	0.18
Top 1% wealth share	0.24	0.04	0.14	0.36
Manufacturing share	0.19	0.08	0.04	0.34
Share small firms	0.50	0.06	0.41	0.67
Share middle-aged	0.49	0.01	0.45	0.52
Share old	0.17	0.03	0.06	0.24
Observations	50			

Notes: S.d. stands for standard deviation.

Table 2.A4: Regression results for the cross-section of US states (longer sample).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	log state personal income				state unemployment rate			
Top 1% share	-0.4	-0.5**	-0.4	-0.2	0.1	0.2	0.08	0.07
	(0.3)	(0.2)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)
Manuf. share		-0.7***	-0.6***	-0.4**		0.4***	0.3***	0.3***
		(0.1)	(0.2)	(0.2)		(0.06)	(0.08)	(0.09)
Share small firms			0.2	0.4*			-0.2	-0.2
			(0.2)	(0.2)			(0.1)	(0.1)
Share mid-aged				-1.8***				0.05
				(0.6)				(0.3)
Share old				-0.9*				0.006
				(0.5)				(0.2)
Observations	50	50	50	50	50	50	50	50
Sample	’69–’07	’69–’07	’69–’07	’69–’07	’76–’07	’76–’07	’76–’07	’76–’07

Notes: Dependent variables are the average IRF of log real state personal income (columns 1–4) and the state unemployment rate (columns 5–8) to a 25 basis points increase in the federal funds rate over a horizon of three years. Sample periods are 1969q1–2007q4 (state personal income) and 1976m1–2007m12 (unemployment). Robust standard errors are reported in parentheses. A * indicates $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.A5: Regression results for the cross-section of US states (State Coincident Index).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Top 1% share	-1.8**	-1.9***	-1.7**	-1.5*	-0.4	-0.6*	-0.3	-0.2
	(0.7)	(0.6)	(0.8)	(0.8)	(0.3)	(0.3)	(0.3)	(0.4)
Manuf. share		-1.2*	-0.9	-0.7		-0.9***	-0.7**	-0.6*
		(0.7)	(0.8)	(0.8)		(0.2)	(0.3)	(0.3)
Share small firms			0.5	1.1			0.5*	0.6*
			(0.9)	(0.9)			(0.3)	(0.3)
Share mid-aged				-5.7**				-1.1
				(2.3)				(1.0)
Share old				-1.5				-0.5
				(1.3)				(0.6)
Observations	50	50	50	50	50	50	50	50
Sample	'84–'07	'84–'07	'84–'07	'84–'07	'79–'07	'79–'07	'79–'07	'79–'07

Notes: Dependent variable is the cumulative IRF of the log State Coincident Index (constructed by the Federal Reserve Bank of Philadelphia) to a 25 basis points increase in the interest rate over a horizon of three years. Robust standard errors are reported in parentheses. A * indicates $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.A6: Regression results for the cross-section of US states (peak response).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Top 1% share	-1.2*	-1.3*	-1.3*	-1.0	0.09	0.05	-0.003	0.2
	(0.6)	(0.7)	(0.7)	(0.8)	(0.2)	(0.3)	(0.3)	(0.3)
Manuf. share		-0.8	-0.8	-0.5		-0.5***	-0.5**	-0.3
		(0.5)	(0.6)	(0.6)		(0.2)	(0.2)	(0.2)
Share small firms			0.04	0.7			-0.10	0.1
			(0.7)	(0.7)			(0.3)	(0.2)
Share mid-aged				-5.5**				-2.5***
				(2.5)				(0.8)
Share old				-1.5				-1.0**
				(1.3)				(0.4)
Observations	50	50	50	50	50	50	50	50
Sample	'84–'07	'84–'07	'84–'07	'84–'07	'69–'07	'69–'07	'69–'07	'69–'07

Notes: Dependent variable is the minimum response of log real state personal income to a 25 basis points increase in the federal funds rate over a horizon of three years. Robust standard errors are reported in parentheses. A * indicates $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.A7: Regression results for the cross-section of US states (fixed effects regressions).

	(1)	(2)	(3)	(4)	(5)	(6)
Top 1% share	-0.6*	-1.8***	-0.8	-0.5	-0.5	-0.6
	(0.3)	(0.6)	(0.6)	(0.5)	(0.5)	(0.5)
Manuf. share				3.0***	2.7***	2.6***
				(0.4)	(0.4)	(0.6)
Share small firms					1.9*	1.1
					(1.0)	(1.4)
Share mid-aged						-1.8
						(1.3)
Share old						5.2*
						(2.8)
Observations	50	50	100	100	100	100
Sample & FE	’69–’88	’88–’07	’69–’07, FE	’69–’07, FE	’69–’07, FE	’69–’07, FE

Notes: Dependent variable is the cumulative IRF of real state personal income to a 25 basis points increase in the interest rate over a horizon of three years. Full sample is cut in half and then a fixed effects regression is conducted (columns 3–6). The first two columns indicate results from estimating equation (2.2) for each of the two subsamples separately. Robust standard errors are reported in parentheses. A * indicates $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Chapter 3

Monetary Policy and Wealth Inequality: The Role of Entrepreneurs

This chapter is joint work with Johannes Wacks.

1 Introduction

Entrepreneurs, private business owners with a tight connection to their firm, form a relatively small fraction of all US households, approximately 7.5%. However, this small group owns about one third of total household wealth and their businesses employ almost half of all workers in the US.[1] Therefore, the investment response of entrepreneurs to an interest rate change can be important for the transmission of monetary policy to aggregate investment, employment, and GDP. During the last 40 years, there has been a shift of wealth towards the already wealthy group of entrepreneurs. Using data from the Survey of Consumer Finances (SCF), we document that the gap between the average net worth held by entrepreneurs and by the rest of the population has widened since the 1980s. In this paper, we investigate the quantitative importance of entrepreneurs and the consequences of the observed shift of wealth towards entrepreneurs for the transmission of monetary policy.

As our main contribution, we develop a Heterogeneous Agent New Keynesian (HANK) model in which a fraction of households are entrepreneurs, who can invest in private businesses with risky returns. The calibrated model yields two main findings. First, entrepreneurs are quantitatively important for the transmission of monetary policy to the real economy, despite being only a small group of households. Second, a more unequal distribution of wealth, caused by a shift of wealth from workers to entrepreneurs leads to larger output effects of monetary policy.

We explicitly distinguish between workers and entrepreneurs. All households, workers and entrepreneurs, can save in a liquid and an illiquid asset. However, entrepreneurs

---

[1] See Cagetti and De Nardi (2006) and De Nardi et al. (2007) and Section 2 below.

have access to an additional investment opportunity, their private firm. This firm operates a decreasing returns to scale technology using labor and capital as inputs. Production of the private firm features idiosyncratic risk. Since households cannot trade private firms and markets are incomplete, entrepreneurs cannot perfectly insure against this idiosyncratic risk.

Because private firms exhibit decreasing returns to scale in production and idiosyncratic risk, an entrepreneur's net worth is a critical determinant of the interest rate elasticity of private firm investment. When monetary policy lowers the interest rate on the government bond, all entrepreneurs optimally rebalance their portfolios away from the risk-free bond and towards their private firms. However, the strength of this reallocation depends on the entrepreneur's net worth. The interest rate elasticity of private firm investment is high for wealthy entrepreneurs. On average, they own large firms and face a relatively low marginal product of capital within their firm due to decreasing returns to scale. Wealthy entrepreneurs are willing to accept small excess returns of firm investment over the risk-free rate because they are well insured and can bear the risk associated with the private firm. When the interest rate falls, the small excess returns of wealthy firm owners increases relatively strongly, so their reallocation response is large. In contrast, the elasticity is low for entrepreneurs with little wealth and small firms. For them, returns from their private business are large compared to the government bond, i.e., they earn high excess returns on private firm investment. An interest rate cut does not increase this excess return much in relative terms, and hence the portfolio reallocation response is small. This portfolio reallocation is a direct effect of an interest rate change by the central bank, and it does not rely on the response of other aggregate variables in general equilibrium.

The poorest entrepreneurs also react strongly to monetary policy, but not because of the portfolio reallocation mechanism just described. Poor entrepreneurs with small businesses could earn large returns from investing in their firms, but borrowing constraints prevent them from expanding their businesses. Hence, their marginal propensity to invest additional income is large. Expansionary monetary policy raises incomes of poor entrepreneurs for two main reasons, which leads to a strong increase of their investment in the private business. First, poor entrepreneurs have taken out private debt to grow their business. Expansionary monetary policy makes debt cheaper and thereby generates a positive income effect for this group of entrepreneurs. Second, expansionary monetary policy stimulates economic activity and generates higher incomes in general equilibrium. Poor entrepreneurs use the additional income to invest heavily into their firm. Taken together, the portfolio reallocation effect, the income effect of an interest rate change and the indirect effects of monetary policy result in an elasticity of private firm investment following an interest rate cut that is U-shaped in net worth, the poorest and the wealthiest entrepreneurs respond most strongly.

We calibrate our model to the US economy. We target the size of the private business sector in terms of employment, as well as the shares of liquid and illiquid assets held by entrepreneurs and workers respectively. Since the distribution of liquid assets crucially determines marginal propensities to consume and invest and affects monetary policy transmission, we also target the shares of hand-to-mouth workers and of hand-to-mouth entrepreneurs.

We test key implications of the model using data from the SCF. First, we show that the average return that entrepreneurs receive from private firm investment diminishes with net worth. Our model matches the empirical distribution of returns from private businesses very well, both unconditionally and conditional on net worth, even though we do not target these statistics in the calibration. Second, we provide direct empirical evidence for the portfolio reallocation mechanism of entrepreneurs. Using identified monetary policy shocks, we document that entrepreneurs increase the share of wealth that they hold in firm capital after a decrease in the federal funds rate. The findings also suggest that this response is heterogeneous across entrepreneurs. In line with our model, both entrepreneurs with low and with high returns react most strongly.

The calibrated model implies an important role for entrepreneurs in the transmission of monetary policy, even though they constitute only a small fraction of all households. The responses of output and aggregate investment are about 50% smaller when entrepreneurs are ignorant about changes in prices and aggregate quantities induced by a monetary policy shock. It is especially important that entrepreneurs take into account the reduction of the interest rate on the government bond, because this stimulates private firm investment. This highlights the importance of the direct effects of monetary policy, specifically the portfolio reallocation effect discussed above.

To understand how wealth inequality affects the transmission of a monetary policy shock, we conduct two experiments. In both, we consider an increase in the share of wealth owned by the richest 10% of households by one percentage point compared to the initial steady state. In the first experiment we compute the approximate aggregate output response to a change in the interest rate for given equilibrium policy functions. We do this once using the actual steady state distribution and once using a counterfactual distribution that exogenously features higher wealth inequality. This exercise has the advantage that we do not need to take a stance on the underlying driver of the increase in wealth inequality. We change the wealth distribution such that the average entrepreneur becomes richer while the average wealth of workers stays unchanged, in accordance with our empirical observations. Under the high-inequality distribution we obtain a 7 to 10% larger output response to an interest rate change, because rich entrepreneurs who react strongly to monetary policy now hold a larger share of wealth.

Second, we re-parameterize the model such that it endogenously generates a more unequal wealth distribution in the steady state. We assume that some entrepreneurs inherit relatively large firms, in contrast to our baseline model in which all households begin their lives without any wealth. This experiment can be viewed as a reduction in estate taxation as observed in the US since the 1980s. We find that the output response to monetary policy is amplified by 3% to 20% relative to the initial economy, depending on how many entrepreneurs receive a positive bequest.

The remainder of this paper is structured as follows. First, we discuss the related literature. In Section 2 we document the importance of entrepreneurs for total household wealth and aggregate employment. In Section 3 we describe our model, which we calibrate in Section 4. We analyze the transmission of monetary policy in Section 5. In Section 6 we provide empirical evidence on the distribution of entrepreneurial business returns that is consistent with core predictions of our model, as well as evidence from identified monetary policy shocks. We investigate the effects of higher wealth inequality on the transmission of monetary policy in Section 7. Section 8 concludes.

Related Literature The importance of entrepreneurs for the US economy has been documented in a number of studies. In particular, Cagetti and De Nardi (2006) and De Nardi et al. (2007) highlight that the average entrepreneur is rich, and that entrepreneurs hold about a third of total US wealth. Asker et al. (2015) estimate that about half of aggregate investment in the US takes place in private firms.

Moreover, two recent empirical studies find that entrepreneurs play an important role for monetary policy transmission. First, Bahaj et al. (forthcoming) document that a significant fraction of the aggregate employment response to expansionary monetary policy shocks in the UK is driven by small and medium-sized enterprises, whose owners' collateral constraints relax due to rising house prices. While the precise channel is absent in our model as we abstract from modeling house prices and collateral constraints, this finding demonstrates that business owners feature strong investment responses to interest rate changes, which is in line with our model. Second, Leahy and Thapar (2019) show that US states with a high fraction of middle-aged households display large responses to expansionary monetary policy shocks. They explain this finding with a high likelihood of being an entrepreneur within this age group and therefore stronger effects, because of strongly increasing entrepreneurial activity in a state. To our knowledge, however, our paper is the first to analyze quantitatively the role of private business owners for the transmission of monetary policy in a structural model.

A surging literature studies how household heterogeneity affects the transmission of monetary policy, often contrasting heterogeneous agent models with representative agent versions (Bilbiie 2008, 2020; Werning 2015). The key distinction between our paper and this strand of literature is that we move beyond a comparison of the polar cases of heterogeneous agent and representative agent models. Instead, we ask how higher wealth inequality, driven by richer entrepreneurs, alters monetary policy transmission.

Kaplan et al. (2018) argue that the distribution of liquid assets matters for the transmission of monetary policy to consumption. While they stress aggregate consumption, the focus of our paper lies on the aggregate investment response to monetary policy.

In addition to workers and a representative firm, which are also present in Kaplan et al. (2018), we model entrepreneurial households, i.e., private business owners. We emphasize a portfolio reallocation channel that is crucial for the aggregate investment response to monetary policy and its dependence on the wealth distribution.

We share the focus on the response of aggregate investment to monetary policy in HANK models with a few recent papers and contribute to a further understanding of the investment response by explicitly modeling private business owners. Luetticke (2021) highlights heterogeneity in marginal propensities to invest (MPI) among households and argues that they are high for wealthy individuals. We focus on the direct effects of monetary policy, in particular the portfolio reallocation of entrepreneurs following interest rate changes. Auclert et al. (2020) demonstrate that while indirect effects of expansionary monetary policy are sizable in general equilibrium, it is the investment decision of firms that sets in motion the feedback loop between higher output and increasing consumption of households with high marginal propensities to consume (MPC). Our model features both, rich heterogeneity among entrepreneurs who crucially determine the direct investment response to monetary policy and high MPCs of workers driving the indirect effects on consumption.

Like us, Melcangi and Sterk (2020) study how the wealth distribution affects the transmission of monetary policy. They focus on stock market participation and portfolio reallocation towards mutual funds as a transmission mechanism of monetary policy, whereas we emphasize the role of private firm investment. Since stock market participation has gone up in the US over time, Melcangi and Sterk (2020) arrive at the same conclusion as we, namely that monetary policy shocks today have greater effects than in the 1980s.

Lastly, our paper is related to recent works by Ottonello and Winberry (2020), Jeenas (2019), and Cloyne et al. (forthcoming) who link the aggregate consequences of monetary policy shocks to the investment activity of heterogeneous firms. These authors concentrate on publicly listed firms, while we focus on privately owned businesses, whose investment decision arguably has a much tighter connection to its owner's balance sheet. The experiment we conduct, changing the distribution of household wealth, is similar to the one in Ottonello and Winberry (2020). They consider a reduction in firm net worth that leads to an increase in default risk. Similar to our results, they find that this dampens the effects of monetary policy shocks. Our paper establishes a connection between these studies on heterogeneous firms and the literature cited above that stresses the importance of household inequality for the transmission mechanism of monetary policy.

2 Entrepreneurs in the US

In this section, we demonstrate the importance of entrepreneurs, i.e., private business owners, for the US economy. We rely on data from the SCF, using 13 waves of the survey between 1983 and 2019. The SCF oversamples wealthy households, which is an important advantage for our analysis compared to other publicly available data sources.

Following Cagetti and De Nardi (2006) and De Nardi et al. (2007), we define a household as an entrepreneur if it meets all the following three criteria:

1. The household head is self-employed
2. The household head owns, or at least partly owns, a private business
3. The household head has an active management role in the business

Only a small share of the population, about 7.5%, qualify as entrepreneurs according to this definition. Moreover, this share has been rather stable over time.[2] Until 1992, the public-use SCF files provide detailed information on the industry of the entrepreneur's firm. We list the share of firms in different industries in 1992 in Appendix A. Typical examples of the entrepreneurial firms in our sample include law firms, medical practices, architect's or accounting offices, and firms in construction services, retail and wholesale business. The small group of entrepreneurial households plays a disproportionate role for several aggregate statistics in the US, as we will document next.

Net worth The average entrepreneur is wealthy. As has already been pointed out by Cagetti and De Nardi (2006), entrepreneurs hold about 33% of total household net wealth. Figure 3.1 documents the share of entrepreneurial households in different parts of the US net worth distribution in 2019. In the bottom 40% of the net worth distribution only about 1.5% of households are entrepreneurs according to our definition. In contrast, one in four households are entrepreneurs among the top 10%, and among the wealthiest one percent every second household owns and manages a private business.

Another way to express the fact that entrepreneurs are relatively rich is to consider how much wealthier the average entrepreneur is compared to the average non-entrepreneur. We plot this ratio in Figure 3.2. Historically, entrepreneurs have been four to eight times wealthier than non-entrepreneurs. This ratio has trended upward over time. While entrepreneurs have always been richer than workers on average, the wealth gap between the average entrepreneur and non-entrepreneur has widened. The time trend is statistically significantly different from zero with a p-value of 0.1%. Excluding the data point in 1983, which could be driving the positive slope, the trend is flatter but remains significant with a p-value of 1.0%.

---

[2] We provide additional graphs, e.g., on the share of entrepreneurs and the aggregate share of wealth held by entrepreneurs over time, in Appendix A.

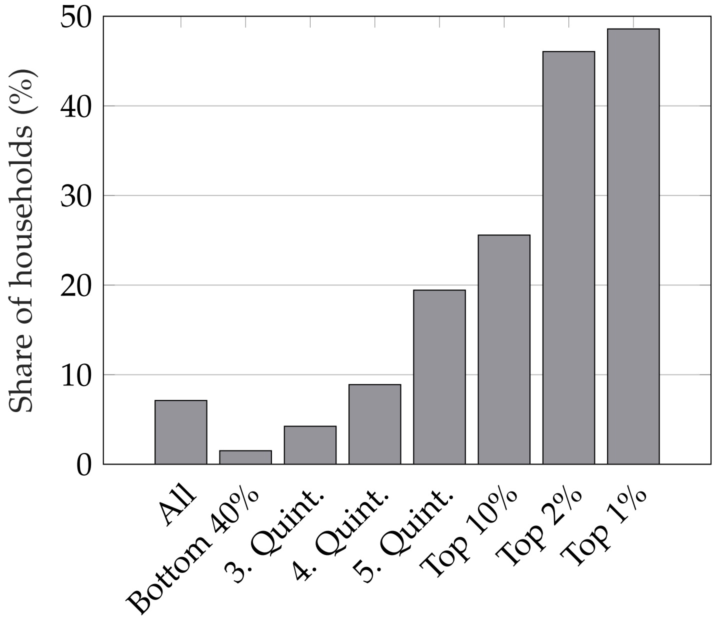


Figure 3.1: Entrepreneurs as a share of all households in different net worth percentiles (SCF 2019).

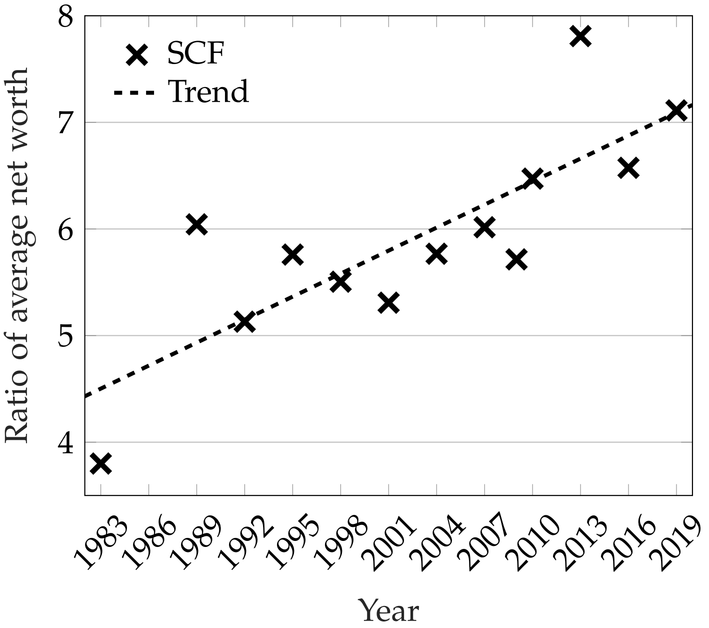


Figure 3.2: Average wealth of entrepreneurs divided by average wealth of non-entrepreneurs.

The fact that (rich) entrepreneurs have become even richer compared to the rest of the population is not surprising, given that wealth inequality in the US has been increasing since the 1980s, as documented, for instance, by Saez and Zucman (2016) and Kuhn et al. (2020).[3] In addition, however, wealth has also become more unequally distributed within the group of entrepreneurs. Figure 3.A5 in the appendix plots the share of total wealth of entrepreneurs held by the wealthiest 10% of entrepreneurs and shows that inequality has gone up over time. In sum, not only has wealth shifted from non-entrepreneurs to entrepreneurs over the recent decades but especially the wealthiest entrepreneurs have become richer.

Employment The importance of entrepreneurs for the US economy is also reflected in the large number of workers who are employed by entrepreneurs' businesses. Starting in 1989, the SCF asks entrepreneurs how many people their businesses employ. We use this question to estimate employment in the firms owned by entrepreneurs as a share of total US employment. It is depicted in Figure 3.3. The employment share is large, about 46% on average between 1989 and 2019, and displays an upward trend over time, similarly to the average wealth ratio. The p-value of the time trend is 1.5%. While entrepreneurs' firms contributed to roughly 40% of US employment in the late 1980s and early 90s, this share has risen to approximately 55% in recent years. The time series displays somewhat more volatility than that of the average wealth ratio in Figure 3.2. This is mostly because, to estimate aggregate employment, we multiply the average employee number from the SCF with the share of entrepreneurial households in the population (Figure 3.A1). The latter series displays some volatility itself.[4] Figure 3.A3 in the Appendix shows that the average employee number is much less volatile and displays a clear upward trend.

The employment numbers likely constitute a lower bound on actual employment at entrepreneurial firms for two reasons. First, entrepreneurs are only asked about employees of the first two businesses that they own. Hence, we do not account for employment in any additional businesses owned.[5] Second, the data on employment in privately held businesses is top coded at 5,000 in the public-use SCF files.[6] Another data limitation is that no information on the intensive margin, i.e., hours worked, is given. Instead, households are merely asked how many people they employ in their business. We do not expect our employment figures to overestimate the true numbers because of this

---

[3] Figure 3.A4 in the Appendix documents the trend of rising wealth inequality in the US, as measured by the share of wealth held by the richest 10% of the population.

[4] We multiply the average number of employees in the entrepreneurs' firms (corrected for the share of ownership in the respective business) with the share of entrepreneurial households in the population (Figure 3.A1). We then multiply the result by total households (TTLHH) and divide by employment level (CE16OV). All time series used here are obtained from the Federal Reserve Economic Database.

[5] About 6% of households that we classify as entrepreneurs in the 2019 SCF own more than two firms. If we assume that entrepreneurs who own more than two businesses employ as many workers in all their additional businesses as they do in their second business, the employment share is 51% on average.

[6] The exact values of the top coding vary over time. While the upper bound reported in the public files of the SCF is at 5,000 employees in 1995 to 2019, this number is 2,500 in 1989 and 25,000 in 1992.

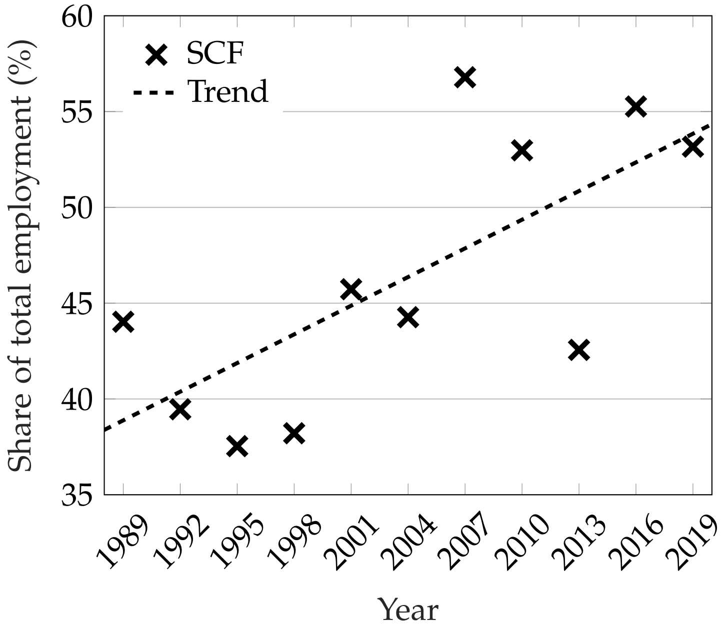


Figure 3.3: Employment in private firms owned by entrepreneurs divided by total US employment.

issue, as part-time workers predominantly work in industries with small numbers of entrepreneurial businesses. We discuss this further in Appendix A.

Investment Unfortunately, the SCF does not contain reliable information about entrepreneurs' investment in their private firms. Asker et al. (2015) estimate that about 53% of aggregate US investment stems from private firms. The relatively restrictively defined group of entrepreneurs, however, includes only a subset of all private firms in the US, so this figure should be considered as an upper bound of investment undertaken by the firms in our sample. Similarly, when comparing total US aggregate investment to data on capital expenditure from Compustat which captures only publicly listed firms (see for instance Gutiérrez and Philippon (2017)), about 40% of aggregate investment is left unexplained and would hence be attributable to private firms.

Firm heterogeneity The average numbers on employment mask significant heterogeneity among entrepreneurial firms, whose distribution is heavily skewed to the right. There exist many firms that are very small and a small portion of firms that are very large, both in terms of employment and in terms of sales. Appendix A reports more detailed statistics on the firm size distribution in our sample. It also shows the distribution of legal statuses, sources of funding, and industry for the entrepreneurial firms in our sample.

3 A HANK Model with Entrepreneurs

In this section we describe our model, which adds a detailed modelling of entrepreneurs to the framework of Kaplan et al. (2018). Since we are interested in the role of wealth inequality for the effects of monetary policy, the model features heterogeneous households with a realistic distribution of wealth and a New Keynesian supply side (HANK model).

Time t is continuous and runs forever. There are two types of households, workers and entrepreneurs. The occupational choice is exogenous and household types are fixed over the lifetime. Workers are subject to uninsurable labor income risk and work either for private firms owned by entrepreneurs or for a representative firm that stands for all publicly listed companies in the economy. Entrepreneurs have access to a private production technology. To produce, they employ their own capital as well as workers, whom they hire on the labor market. Private firms and the representative listed firm produce the same homogeneous intermediate good. Firms facing monopolistic competition and price adjustment costs differentiate this intermediate good. They sell the differentiated goods to a final goods producing firm which bundles them into a final output good that is consumed and used for investment. The government consists of a fiscal authority, which levies taxes on households and distributes transfers to them, and a monetary authority which controls the nominal interest rate. All risk is of idiosyncratic nature, there is no aggregate risk. The monetary policy shock we consider later on is a one-time, unexpected ("MIT") shock.

3.1 Households

At any point in time, the economy is populated by a unit mass of households. An exogenous mass s_e of these households are entrepreneurs, and mass $1 - s_e$ are workers. Each household dies stochastically at rate ζ and is then replaced by a newborn household. Households start their lives with a draw from the stationary distribution of the productivity process and as the same type (worker or entrepreneur) as the household they are replacing. In our baseline specification, households begin their lives with zero assets as in Kaplan et al. (2018). In Section 7 we compare the effects of monetary policy shocks in this baseline specification to one in which entrepreneurs are born with positive assets, which leads to higher wealth inequality.

All households value consumption c_t and dislike labor ℓ_t in the same way. Their preferences are time separable and households discount the future at rate ρ. Taking into account the constant dying intensity ζ, households' preferences over consumption-labor processes $\{c_t, \ell_t\}$ are given by the utility function

$$U\left(\{c_t, \ell_t\}\right) = \mathbb{E} \int_{t=0}^{\infty} e^{-(\rho+\zeta)t} u(c_t, \ell_t) \mathrm{d}t, \tag{3.1}$$

where the felicity function $u(c, \ell)$ is additively separable in consumption and labor, monotonically increasing in c and monotonically decreasing in ℓ. It is further strictly concave in both arguments and satisfies $\lim_{\ell \to 0} u_\ell(c, \ell) = 0$ and $\lim_{c \to 0} u_c(c, \ell) = \infty$.

We now describe the entrepreneurs in detail. Afterwards, we turn to the workers, who face the same problem as in Kaplan et al. (2018).

Entrepreneurs Entrepreneurs can invest in three assets. The first is a liquid asset b_t, the second is an illiquid asset a_t, and the third is their private firm of size k_{et}. While the first two are risk-free, investment in the private firm is risky.

We think of the liquid asset as cash and directly held government bonds. The illiquid asset captures houses (net of mortgages), shares in publicly traded firms and pension accounts. Investment in the liquid asset is costless and offers the risk-free return r_t^b. Investment in the illiquid asset is costly. When depositing or withdrawing d_t from the illiquid account of size a_t, the household has to pay a portfolio adjustment cost $\chi^a(d_t, a_t)$. We denote by r_t^a the interest rate earned on the illiquid account. Borrowing is only possible in the liquid asset and only up to a borrowing limit $-\underline{b}$. The interest rate on negative liquid asset holdings exceeds the rate on positive holdings by a constant borrowing wedge κ

$$r_t^b(b_t) = r_t^b + \kappa \cdot \mathbb{1}\{b_t < 0\}.$$

The household cannot hold a negative position of the illiquid asset, $a_t \geq 0$. Due to the adjustment costs, households are only willing to invest in the illiquid account if it yields a higher return, such that in equilibrium we will have $r_t^a > r_t^b$.

In addition to these two assets, entrepreneurs can invest in the capital of their own private firm $k_{et} \geq 0$, whose shares are non-tradable. We denote investment in the private firm by f_t. Entrepreneurs disinvest if $f_t < 0$. If an entrepreneur wants to grow or shrink her firm she has to pay capital adjustment costs $\chi^e(f_t, k_{et})$. Hence, private business capital constitutes a second illiquid asset in the economy. What distinguishes the illiquid asset a from private firm capital k_e is the associated risk. While investment into a is risk-free, investment into the private firm is risky. We specify the sources of this risk after describing the entrepreneurs' production technology.

In order to produce output, entrepreneurs hire labor n_{et} from workers, whom they pay the real wage w_t. The amount of invested capital k_{et} together with the household's productivity and hired labor then determines production of the entrepreneur according to the decreasing returns to scale production function

$$y_e(y, k_e, n_e) = Z_e \cdot y \cdot \left(k_e^\alpha \cdot {n_e}^{1-\alpha}\right)^\nu,$$

with $\nu \in (0, 1)$. The parameter $Z_e > 0$ governs the productivity of the entrepreneurial sector relative to the representative firm, whose productivity we normalize to one and whom we describe in more detail below.

Decreasing returns to scale are common in the literature on entrepreneurship (Cagetti and De Nardi 2006; Tan 2021). They are of key importance for the portfolio re-allocation mechanism that we emphasize in this paper. The assumption goes back to Lucas (1978) who motivates it using diminishing returns on span-of-control. The entrepreneur's ability in managing the firm gets stretched out over ever larger projects, and accordingly, the productivity of the firm suffers.[7] Decreasing returns to scale have the consequence that wealthier entrepreneurs earn lower returns from their firm. This implication is in line with recent findings in Boar et al. (2022) and Xavier (2021), and we provide additional evidence in Section 6.1.

There are two sources of idiosyncratic investment risk. The first is productivity risk. Current productivity of an entrepreneur y_t evolves stochastically according to some process

$$\dot{y}_t = \Phi_y(y_t).$$

The second source of risk is a capital quality shock that affects the capital employed in the firm k_{et}. Firm capital evolves over time according to the following process:

$$\mathrm{d}k_{et} = [f_t - \delta \cdot k_{et}]\,\mathrm{d}t + \sigma_k \cdot k_{et} \cdot \mathrm{d}W_t \ ,$$

where W_t is a Wiener process, σ_k the standard deviation of the capital quality shock and δ denotes the depreciation rate.

Entrepreneurs themselves work an exogenously fixed amount of hours, $\bar{\ell}$, on tasks regarding the management of the firm. Their labor input does not enter the production function.[8] Entrepreneurs are not paid wages, compensation for their work is included in the profits that they receive from their firm. Denoting by p_t the real price of output produced by entrepreneurs at time t, we can define entrepreneurial profits before taxes as

$$\Pi_e(k_{et}, y_t) = p_t \cdot y_e(k_{et}, n^*_{et}, y_t) - w_t \cdot n^*_{et} \ .$$

Here, we have already substituted in the optimal labor demand of the entrepreneurs n^*_{et}, which is a static decision and given by

$$n^*_{et} = \left(\frac{p_t \cdot (1-\alpha) \cdot \nu \cdot Z_e \cdot y_t \cdot k_{et}^{\alpha\nu}}{w_t} \right)^{\frac{1}{1-\nu(1-\alpha)}} \ .$$

---

[7] An alternative motivation for arriving at decreasing returns to scale in revenues is to assume constant returns to scale in production and a downward-sloping demand curve for the entrepreneur's output y_e (Cooley and Quadrini 2001; Asker et al. 2014).

[8] The precise number of hours worked by the entrepreneurs, $\bar{\ell}$, is irrelevant in all what follows, as utility is additively separable in consumption and labor.

Taken together, entrepreneurs maximize utility solving the problem

$$
\begin{aligned}
&\max_{\{c_t, b_t, d_t, f_t\}} U\left(\{c_t, \bar{\ell}\}\right) && (3.2)\\
\text{subject to: } \quad & \dot{b}_t = (1-\tau_e)\cdot \Pi_e(k_{et}, y_t) + r_t^b(b)\cdot b_t - d_t - f_t + T_t - c_t \\
& \qquad - \chi^a(d_t, a_t) - \chi^e(f_t, k_{et}) + \tau_e \cdot \delta \cdot k_{et} \\
& \dot{a}_t = r_t^a \cdot a_t + d_t \\
& \dot{k}_{et} = f_t - \delta \cdot k_{et} + \sigma_k \cdot k_{et} \cdot \dot{W}_t \\
& b_t \geq -\underline{b},\ a_t \geq 0,\ k_{et} \geq 0,
\end{aligned}
$$

given initial conditions. Here, T_t denotes a lump-sum transfer from the government. The proportional tax on business income τ_e only pertains to profits after depreciation, which gives rise to the tax deduction term $\tau_e \cdot \delta \cdot k_{et}$.

Note that we understand the interest rate on each of the three assets as implicitly augmented by ζ. This accounts for the fact that accidental bequests from deceased households are distributed to the living households in proportion to their current assets, i.e., there are perfect annuity markets.

Firm dynamics As occupational choice is exogenous, there is no endogenous entry and exit of firms. However, households die with probability ζ and are then replaced by households of the same type with zero assets. Hence, exogenous entry and exit exists in our model, and we observe both very large and very small firms in equilibrium.

Workers Like entrepreneurs, workers can invest in the liquid asset b, and the illiquid asset a, but unlike entrepreneurs they cannot run private firms. Instead, they earn labor income and make a continuous labor supply decision on work hours $\ell_t \in [0,1]$. They supply this labor to the representative firm or to the private firms and are indifferent between these two options, as they receive the same wage in both cases. Wage payments are subject to a proportional labor tax τ_l. Workers receive idiosyncratic shocks to their labor productivity, whose natural logarithm z_t evolves according to some exogenous stochastic process,

$$\dot{z}_t = \Phi_z(z_t).$$

Workers maximize utility solving the problem

$$
\begin{aligned}
&\max_{\{c_t, \ell_t, b_t, d_t\}} U\left(\{c_t, \ell_t\}\right) && (3.3)\\
\text{subject to: } \quad & \dot{b}_t = (1-\tau_l)\cdot w_t \cdot \exp(z_t)\cdot \ell_t + r_t^b(b)\cdot b_t - \chi^a(d_t, a_t) - d_t + T_t - c_t, \\
& \dot{a}_t = r_t^a \cdot a_t + d_t \\
& b_t \geq -\underline{b},\ a_t \geq 0,
\end{aligned}
$$

given initial conditions.

In Appendix B we provide the Hamilton-Jacobi-Bellman equations that characterize the solutions to the household problems recursively for the specific process for z_t and y_t described in Section 4.

3.2 Production

The economy features a standard New Keynesian supply side with one complication: The first layer of production does not only consist of a representative listed firm which uses capital and labor to produce. Rather, all entrepreneurs as well as the representative firm produce input goods that are perfectly substitutable (see Figure 3.4). Monopolistically competitive intermediate goods producers differentiate the input goods. These intermediate goods producers are subject to price adjustment costs as in many standard New Keynesian models. Lastly, the differentiated intermediate goods are sold to a final goods producer, who bundles them and produces the final good which is used for consumption and investment.

The representative firm employs labor N_{pt} and capital K_{pt} to produce output Y_{pt} which it sells at price p_t. This is the same price at which entrepreneurs sell their production because both produce an identical good. The representative firm operates a Cobb-Douglas production function

$$Y_{pt} = N_{pt}^{1-\alpha} K_{pt}^{\alpha}.$$

Profit maximization requires that factor prices equal marginal products

$$\begin{aligned} r_t^k &= p_t \cdot \alpha \cdot \left(\frac{K_{pt}}{N_{pt}} \right)^{\alpha-1} \\ w_t &= p_t \cdot (1-\alpha) \cdot \left(\frac{K_{pt}}{N_{pt}} \right)^{\alpha} . \end{aligned}$$

There is a continuum of mass one of monopolistically competitive intermediate goods producers. Intermediate good producer j buys the amount $Y_{et}(j)$ of the general input good from entrepreneurs and the amount $Y_{pt}(j)$ from the representative firm at price p_t, and produces a differentiated variety $Y_t(j)$ using the linear technology

$$Y_t(j) = Y_{et}(j) + Y_{pt}(j) .$$

Intermediate good producer j sets a nominal price $P_t(j)$ for its intermediate good variety to maximize the present value of real profits. When setting the price, the intermediate good producer takes into account price adjustment costs and the demand schedule $Y^d \left(\frac{P_t(j)}{P_t} \right)$, where P_t denotes the aggregate price level. Price adjustment costs are of the

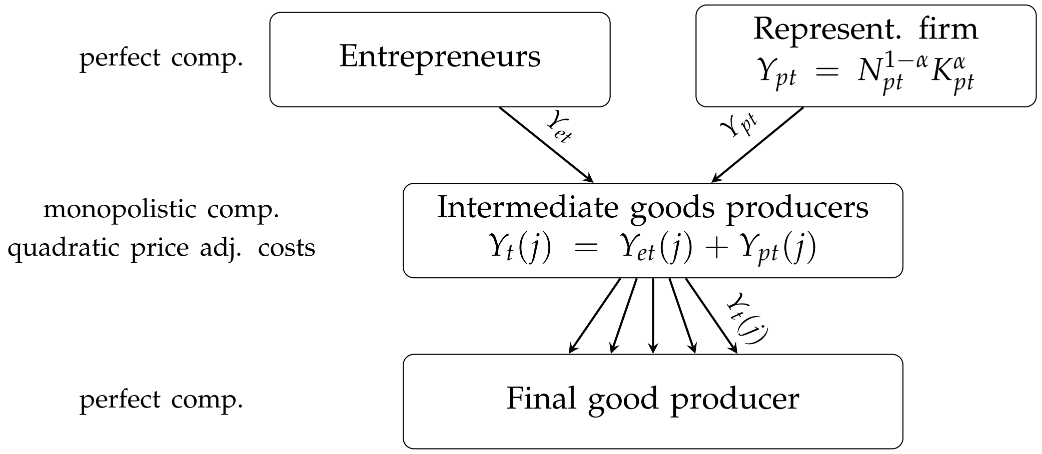


Figure 3.4: Production flow.

quadratic form as in Rotemberg (1982)

$$\Theta\left(\frac{\dot{P}_t(j)}{P_t(j)}\right) = \frac{\theta}{2}\cdot\left(\frac{\dot{P}_t(j)}{P_t(j)}\right)^2 \cdot Y_t\,,$$

where Y_t denotes final output and the parameter θ determines the level of price adjustment costs.

The firm discounts the future at rate r_t^a. This is the rate of return of the mutual fund which owns the firm's shares as described below. The maximization problem of an intermediate goods producer is then

$$\max_{\{P_t(j)\}_{t\geq 0}} \int_{t=0}^{\infty} e^{-\int_0^t r_s^a \mathrm{d}s}\left[\left(\frac{P_t(j)}{P_t} - p_t\right)\cdot Y^d\left(\frac{P_t(j)}{P_t}\right) - \Theta\left(\frac{\dot{P}_t(j)}{P_t(j)}\right)\right]\mathrm{d}t. \tag{3.4}$$

This notation makes it clear that the price of the input goods p_t acts as the real marginal cost of the intermediate goods producers, $mc_t \equiv p_t$.

The demand schedule is derived from the profit maximization problem of a final good producing firm which combines the intermediate goods into the final output good Y_t according to the production function

$$Y_t = \left(\int_0^1 Y_t(j)^{1-\frac{1}{\epsilon}}\,\mathrm{d}j\right)^{\frac{\epsilon}{\epsilon-1}}.$$

Profit maximization of the final goods producer yields the demand for intermediate goods

$$Y^d\left(\frac{P_t(j)}{P_t}\right) = \left(\frac{P_t(j)}{P_t}\right)^{-\epsilon}\cdot Y_t,$$

such that $\epsilon > 0$ is the demand elasticity for intermediate goods. We show in Appendix B that this demand function together with the profit maximization problem of the intermediate goods producer yields the New Keynesian Phillips curve

$$\left(r_t^a - \frac{\dot{Y}_t}{Y_t}\right)\pi_t = \frac{\epsilon}{\theta}\left[mc_t - \frac{\epsilon - 1}{\epsilon}\right] + \dot{\pi}_t, \tag{3.5}$$

where $\pi_t = \frac{\dot{P}_t}{P_t}$ denotes the inflation rate. Per-period profits net of price adjustment costs are

$$\Pi_t = (1 - mc_t) \cdot Y_t - \frac{\theta}{2} \cdot \pi_t^2 \cdot Y_t.$$

3.3 Mutual fund and profits from intermediate goods producers

Households' holdings of the illiquid asset a_t are managed by a mutual fund. The fund owns capital K_{pt} which it rents out to the representative firm at rate r_t^k, and it invests in shares of the intermediate goods producers, which trade at price q_t.

Intermediate goods producers pay out a fraction $\omega \cdot \frac{Y_{pt}}{Y_t}$ of profits as dividends, where $\omega \in [0, 1]$ is a parameter. The fraction $(1 - \omega)$ is paid out to the workers as a transfer into their liquid account, in proportion to their current labor productivity.[9] These payments can be interpreted as bonuses. The remaining share $\omega \cdot \left(1 - \frac{Y_{pt}}{Y_t}\right) = \omega \cdot \frac{Y_{et}}{Y_t}$ of profits are paid into the liquid account of the entrepreneurs in proportion to the output of their firm. Hence, entrepreneurs share in the profits of their customers. Splitting up profits Π_t in this fashion ensures that the movement of profits following a monetary policy shock similarly affects investment into the private and into the representative firm.

We normalize the total number of shares to one. Optimality of the portfolio allocation requires that the returns on both investments are the same,

$$\frac{\omega \cdot \frac{Y_{pt}}{Y_t} \cdot \Pi_t + \dot{q}_t}{q_t} = r_t^k - \delta = r_t^a. \tag{3.6}$$

3.4 Government

The government consists of a fiscal and a monetary authority. The fiscal authority collects taxes on labor income (including the part of profits that is paid into the liquid account of workers) and issues real bonds denoted by B^S, which assumes a positive value when the government has debt. It pays out transfers to the households and spends an amount G on government expenditures. The government balances its budget in every instant

$$G + r_t^b B^S + T_t = \tau_l(w_t N_t + (1 - \omega)\Pi_t) + \text{Rev}_{et}, \tag{3.7}$$

where N_t denotes aggregate labor supply, and Rev_{et} denotes revenues from taxing entrepreneurial profits, all defined in Appendix B.1.

---

[9] This is analogous to the treatment of profits in Kaplan et al. (2018), where $Y_p = Y$ as they do not model an entrepreneurial sector.

The monetary authority sets the nominal interest rate $i_t = r_t^b + \pi_t$ following a Taylor rule

$$i_t = \bar{r} + \phi \pi_t + \varepsilon_t, \tag{3.8}$$

where ε_t denotes a monetary policy shock. It is zero in steady state. Below we consider the effects of an unexpected change of ε_t followed by a return back to zero at rate $\eta = 0.5$

$$\varepsilon_t = \exp(-\eta t) \cdot \varepsilon_0.$$

3.5 Equilibrium

We define the equilibrium in Appendix B.1. The distribution of workers over the state space (b, a, z) and the distribution of entrepreneurs over (b, a, k_e, y) are equilibrium objects as they determine the aggregate demand for assets and entrepreneurial production, and thereby equilibrium prices. We denote by μ_{wt} the distribution of workers over the state space (b, a, z), and by μ_{et} the distribution of entrepreneurs over (b, a, k_e, y). Both of these distributions integrate to one at every point in time. We refer to the joint distribution of the two household types as μ_t. We index households by i, and denote by $\mu_t(i)$ the mass of household i.

4 Calibration

Wherever possible, our calibration strategy closely follows Kaplan et al. (2018). We use the same income process for workers and the same values for the externally calibrated parameters presented them in Table 3.1. We only discuss these briefly in the next subsection. Our strategy for the calibration of the remaining parameters, especially those governing the behavior of entrepreneurs, is described in Section 4.2.

4.1 Externally calibrated parameters and functional forms

The felicity function is

$$u(c, \ell) = \log(c) - \varphi \frac{\ell^{1+\gamma}}{1+\gamma},$$

where we set γ equal to 1 and φ to 2.2. These choices imply an intertemporal elasticity of substitution of one, a Frisch elasticity of labor supply of one and an average labor supply of approximately 0.5.

Households die at rate $\zeta = \frac{1}{180}$, which implies an average life span of 45 years. The borrowing limit, $\underline{b}$, is set to the average quarterly labor income. The portfolio adjustment

Table 3.1: Externally calibrated parameters.

Parameter		Value	Description	Source or Target
Demographics	s_e	7.5%	share entrepreneurs	SCF
	ζ	1/180	death rate	avg. lifetime 45 years
Preferences	φ	2.2	labor disutility	avg. working time 8h/day
	γ	1	Frisch elasticity	KMV
Technology	$\underline{b}$	1	borrowing limit	avg. qarterly labor inc.
	α	0.33	capital share	KMV
	ω	0.33	dividend ratio	equal to capital share α
	ϵ	10	demand elast. intermediates	mark-up 11%
	θ	100	price adjustment cost	slope of Phillips curve 0.1
	δ	0.07/4	depreciation rate	7% p.a.
	ν	0.79	returns to scale	Tan (2021)
Policy	ϕ	1.25	inflation response	KMV
	τ_l	0.3	tax rate on labor income	KMV
	τ_e	0.3	tax rate on business income	same as on labor τ_l
	T_t	$0.06 \cdot Y_t$	lump-sum transfers	KMV
	$\bar{r}$	0.02/4	steady state interest rate	2% p.a.

Notes: Rates are expressed as quarterly values. KMV stands for Kaplan et al. (2018).

cost function for the illiquid asset a is a convex function as in Alves et al. (2020)

$$\chi^a(d,a) = \chi_1^a \cdot \left(\frac{|d|}{a}\right)^{\chi_2^a} \cdot a,$$

where χ_1^a and χ_2^a are parameters.

For worker i, log productivity z_{it} consists of two additive parts, a transitory component $z_{1,it}$ and a more persistent component $z_{2,it}$,

$$z_{it} = z_{1,it} + z_{2,it}.$$

Each of the two components follows a jump-drift process, with jumps arriving at rate λ_{zj} for $j = 1, 2$. At all times, the process drifts toward its mean of zero at rate β_{zj}. Whenever there is a jump, a new productivity state is drawn from a normal distribution, with $z'_{j,it} \sim N(0, \sigma_{zj}^2)$. Hence, we have

$$\mathrm{d}z_{j,it} = -\beta_{zj} \cdot z_{j,it} + \mathrm{d}J_{j,it},$$

where $\mathrm{d}J_{j,it}$ captures the jumps in the process. The parameters for this process are shown in Table 3.2. This is the same income process as in Kaplan et al. (2018), and we refer the reader to their paper for a more detailed discussion. Importantly, the income process ensures that the variance and the kurtosis of the innovations of the modeled income

Table 3.2: Parameters of the income process.

	β_{zj}	λ_{zj}	σ_{zj}
$j = 1$	0.761	0.080	1.74
$j = 2$	0.009	0.007	1.53

process correspond to those estimated from social security data by Guvenen et al. (2021).

The output elasticity of capital, α, assumes a value of 0.33 and capital depreciates at 7% annually. The parameter governing the fraction of profits that is automatically reinvested into the illiquid account, ω, is set equal to α. This sterilizes the effect of cyclical profits on investment (see Kaplan et al. 2018). The demand elasticity faced by the intermediate goods producers, ϵ, is set to 10. A value of $\theta = 100$ for the price adjustment costs then ensures that the slope of the Phillips curve is 0.1. The parameter governing the response of the central bank to inflation, ϕ, is set to 1.25. We set the government bond supply such that the steady state interest rate on the liquid asset is 2% annually. The lump-sum transfer to the households is set to 6% of GDP and the tax rate on labor income τ_l to 30%.

4.2 Entrepreneurial sector

We set s_e to 7.5%, the average share of entrepreneurs in the US population over the previous decades. We take the degree of decreasing returns in production for private firms ν from Tan (2021), who estimates a value of 0.79.[10] Since most of the entrepreneurial businesses in the SCF are sole proprietorships, partnerships or S corporations (see Table 3.A3 in the appendix), which are all subject to pass-through taxation, i.e., business income is not taxed within the company but reported as personal income, we set $\tau_e = \tau_l = 30\%$. Recent evidence in Acemoglu et al. (2020) shows that this is a reasonable approximation for the average tax rate on S corporations and C corporations.

Stochastic productivity process $\Phi_y(y_t)$ Productivity y of entrepreneurs can take on two values. We interpret the low productivity state, y_l, as a low-talent or subsistence entrepreneur (Poschke 2013). The other state, y_h, captures highly talented entrepreneurs or opportunity entrepreneurs. We normalize $\mathbb{E}[y] = 1$, keeping in mind that the parameter Z_e captures overall productivity of the entrepreneurial sector.

Transitions between the two states happen stochastically, at Poisson rate $\lambda_{y,lh}$ from low to high, and at rate $\lambda_{y,hl}$ from high to low state. We assume that switches between the two states take place only very infrequently, and we interpret them as "career shocks",

---

[10] Tan (2021) estimates this value using detailed data on private start-ups, relatively young firms by definition. We also experimented with a value of $\nu = 0.88$, which is the value used by Cagetti and De Nardi (2006), but results are largely unchanged.

similarly to the persistent component z_2 of workers' labor productivity in Kaplan et al. (2018). Accordingly, we calibrate the transition intensities between the two states to occur on average every 38 years.[11] We further assume that 12.3% of entrepreneurs are of the low (subsistence) type, a number we take from Poschke (2013). This then uniquely pins down the transition intensities, $\lambda_{y,lh} = 0.04$ and $\lambda_{y,hl} = 0.006$. At the end of this section we verify that the business income process faced by entrepreneurs in our model is comparable to its data analogue estimated in DeBacker et al. (forthcoming).

Capital adjustment costs The entrepreneurial capital adjustment cost function is of a quadratic form

$$\chi^e(f, k_e) = \chi_1^e \cdot \left(\frac{f - \delta \cdot k_e}{k_e}\right)^2 \cdot k_e \, ,$$

where χ_1^e is a parameter. This specification ensures that replacing depreciated capital entails no adjustment cost.

4.3 Calibration targets

This leaves us with eight parameters to calibrate. We target the ratio of liquid assets to GDP (0.26), the ratio of illiquid assets to GDP (2.92), the fraction of poor hand-to-mouth households (i.e., those with few liquid and no illiquid assets, 10%), and the fraction of wealthy hand-to-mouth households (few liquid but positive illiquid assets, 20%) to pin down the discount rate ρ, the borrowing wedge κ, and the portfolio adjustment cost function parameters χ_1^a and χ_2^a. The targeted hand-to-mouth shares refer to households of both occupations, i.e., workers and entrepreneurs. We take these targets from Kaplan et al. (2018).[12]

The remaining four parameters are specific to the entrepreneurial sector in our model. These are the parameters governing the productivity of the entrepreneurial sector, Z_e, the productivity gap between low and high talent types, y_h/y_l, the standard deviation of the capital quality shock, σ_k, and the capital adjustment cost function parameter, χ_1^e.

We use the average employment share of 46% that we found in the SCF to pin down productivity in the entrepreneurial sector. We also want to match the average portfolio composition of entrepreneurs, as their portfolios and the portfolio reallocation following a monetary policy shock are the focus of our analysis. To this end, we target the share of liquid assets (b) in the US economy that are held by entrepreneurs, on average 22% across all SCF waves, the share of illiquid assets (a, i.e., not counting private firms) held

---

[11] This is also the frequency of jumps in the persistent component of workers' productivity process, i.e., we impose $\pi_l \cdot 1/\lambda_{y,lh} + (1 - \pi_l) \cdot 1/\lambda_{y,hl} = 1/\lambda_{z2}$, where π_l denotes the mass of entrepreneurs of the low type in the stationary distribution.

[12] Kaplan et al. (2018) calibrate an additional third parameter for the intercept of the portfolio adjustment cost function. We follow Alves et al. (2020) and set it to zero to reduce the number of parameters to be calibrated internally from nine to eight.

Table 3.3: Internally calibrated parameters.

Parameter	Value	Description	Target
ρ	0.018	discount rate	Liquid assets to GDP
κ	0.015	borrowing wedge	Illiquid assets to GDP
χ_1^a	0.84	portf. adj. costs	Share wealthy HtM
χ_2^a	1.45	–	Share poor HtM
Z_e	2.01	avg. entrep. talent	Empl. share in entrep. firms
y_h/y_l	1.86	spread entrep. talent	Share illiq. assets held by entrep.
σ_k	0.12	capital qual. shock	Share liq. assets held by entrep.
χ_1^e	0.50	adj. costs firm	Share HtM entrepreneurs

by entrepreneurs (also 22%), and the share of entrepreneurs that are hand-to-mouth (16%).[13]

While the identification of any single parameter cannot be traced back to one single target, there still exist tight linkages between our targets and the calibrated parameters. Capital quality shocks occur frequently in our model, so that entrepreneurs use liquid assets to insure against them. Hence, the share of liquid assets they hold informs σ_k. In contrast, talent shocks occur very infrequently, and thus entrepreneurs insure against these shocks using the illiquid asset a. This makes the share of illiquid assets held by entrepreneurs a useful target to inform the productivity of opportunity entrepreneurs relative to subsistence entrepreneurs y_h/y_l. Lastly, when capital adjustment costs are high, entrepreneurs grow their firm relatively slowly at the beginning of their lives. Thus, relatively few of them are up against the borrowing constraint $\underline{b}$.[14] If adjusting capital is cheap, growing the firm quickly in the beginning, all the while facing binding borrowing constraint, becomes more attractive. Therefore, the share of hand-to-mouth entrepreneurs informs the capital adjustment cost parameter χ_1^e.

Table 3.3 lists the calibrated parameters. The first four, also calibrated in Kaplan et al. (2018), are very close to the values that they find. In terms of parameters regarding the entrepreneurial sector, we find that more productive entrepreneurs (y_h) are about twice as productive as the low-productive ones (y_l). There exists considerable short-term income and investment risk for entrepreneurs, as a capital quality shock of one standard deviation implies a 12% lower or higher capital stock. Lastly, the capital adjustment cost parameter χ_1^e is in the same range as the linear component of the portfolio adjustment cost function, χ_1^a.[15] Table 3.4 documents that for these calibrated parameters the model matches the eight targets relatively well.

---

[13] We construct hand-to-mouth shares in the SCF following the procedure in Kaplan et al. (2014).

[14] As mentioned before, all entrepreneurs start their lives with a firm of size $k_e = 0$.

[15] Be reminded, however, that in order to conserve on parameters to be calibrated we have set the parameter governing the convexity of the capital adjustment cost function $\chi^e(\cdot)$ to 2. This is higher than the calibrated convexity parameter of the portfolio adjustment cost function, χ_2^a.

Table 3.4: Targeted moments.

	$\frac{K}{Y}$	$\frac{B}{Y}$	pHtm	wHtm	Lab. at e.	Liq. e.	Illiq. e.	Htm e.
Data	2.92	0.26	0.10	0.20	0.46	0.22	0.22	0.16
Model	2.65	0.27	0.10	0.20	0.41	0.21	0.24	0.16

Notes: $\frac{K}{Y}$ is the capital to output ratio, $\frac{B}{Y}$ liquid assets to output, *pHtm* and *wHtm* are the shares of households who are poor and wealthy hand-to-mouth respectively, *Lab at e.* is the share of labor at private businesses, *Liq e.* and *Illiq e.* are the shares of liquid (b) and illiquid (a) assets held by entrepreneurs respectively, *Htm e.* is the share of entrepreneurs who are hand-to-mouth.

Table 3.5: Share of entrepreneurs by net worth percentiles in %.

	All	1.+2. Q.	3. Q.	4. Q.	5. Q.	Top 10%	Top 2%	Top 1%
Model	7.5	0.9	2.2	4.8	28.8	43.9	60.9	65.9
SCF 2019	7.1	1.5	4.2	8.9	19.4	25.6	46.1	48.6

Notes: Q. stands for Quintile.

4.4 Untargeted moments

In Table 3.5 we compare the joint distribution of occupation and wealth in the steady state of the model, which was not targeted in our calibration, with the SCF data. The table shows the probability that a randomly selected household from a specific percentile of the wealth distribution is an entrepreneur. The numbers from the SCF correspond to those shown in Figure 3.1. The model matches the data relatively well, although it overstates the likelihood of entrepreneurs appearing at the very top of the wealth distribution. For this reason, the ratio of average wealth held by entrepreneurs and by workers is higher (approximately eleven) in our model than it is in the data (six on average). In terms of overall wealth inequality in our model economy we perform relatively well, as can be seen in Table 3.6.

We calibrated the income process for entrepreneurs, in particular the standard deviation of the capital quality shock, σ_k, and the spread between the productivity of high- and low-productivity entrepreneurs, to match aggregate targets in our calibration. To assess whether the calibrated income process resembles that observed in the data, we resort to recent results by DeBacker et al. (forthcoming), who use a large confidential panel of US income tax returns to scrutinize business income risk faced by households.

Table 3.6: Shares of wealth held by different groups of the net worth distribution in %.

	Bottom 50%	Top 20%	Top 10%	Top 1%
Model	0.2	92.5	81.5	36.1
SCF 2019	0.1	87.4	76.5	37.2

Table 3.7: Annual transition matrix of business income ($\underline{\text{Model}}$/Data), in %.

	1. Quint.	2. Quint.	3. Quint.	4. Quint.	5. Quint.
1. Quint.	$\underline{40}$ / 63	$\underline{24}$ / 19	$\underline{14}$ / 8	$\underline{11}$ / 5	$\underline{11}$ / 5
2. Quint.	$\underline{19}$ / 18	$\underline{39}$ / 49	$\underline{23}$ / 21	$\underline{13}$ / 8	$\underline{6}$ / 4
3. Quint.	$\underline{13}$ / 7	$\underline{19}$ / 20	$\underline{33}$ / 47	$\underline{22}$ / 22	$\underline{12}$ / 4
4. Quint.	$\underline{12}$ / 5	$\underline{13}$ / 7	$\underline{19}$ / 18	$\underline{34}$ / 53	$\underline{23}$ / 16
5. Quint.	$\underline{15}$ / 5	$\underline{5}$ / 3	$\underline{10}$ / 4	$\underline{21}$ / 14	$\underline{49}$ / 75

Notes: The table reports the probability of moving from the row quintile of business income to the column quintile within one year. The data (right values) are from DeBacker et al. (forthcoming). We use the values from their Table 1. We delete their first row and column (corresponding to zero earnings), reweigh the remaining entries such that rows sum to one again, and then consolidate deciles into quintiles. Values from our model (left) are based on a simulation of 10,000 entrepreneurs over two years. We measure business income as $[\Pi_e(k_{et}, y_t) - f_t] \cdot \mathrm{d}t + \mathrm{d}k_{et}$, i.e., as profits net of costs and depreciation.

Their definition of business income includes the sum of income generated from sole proprietorships, partnerships, and S corporations, and refers to the net profit or loss from business operations after all expenses, costs, and deductions have been subtracted. They do not require households to be actively managing or owning a business, as we do, but we still find it worthwhile to compare the results on income dynamics they report to those generated from our model.

In particular, DeBacker et al. (forthcoming) report how likely it is for households to move from a given decile of the business income distribution to another decile in the following year. Table 3.7 shows these numbers, as well as the analogous statistics simulated from our model. For better readability we reduce the dimension of the transition matrix from ten deciles to five quintiles. The matrix in DeBacker et al. (forthcoming) contains transition probabilities to and from a separate state with "no business income" alongside the ten deciles of the business income distribution. Since the probability of zero business income is zero in our model, we delete the zero income state and reweight the original transition matrix in DeBacker et al. (forthcoming). This way, we can compare transition probabilities between quintiles of the business income distribution in the model and the data conditional on non-zero business income. In sum, we find that the income process in our model is similar to that in the data, though ours features somewhat more volatility. Also in the data, households face substantial fluctuations in business income, represented by relatively small probabilities of staying in the same earnings quintile year-on-year. The immobility ratio, i.e., the average of the diagonal elements of the transition matrix, is 39% in our model and 57% in the data.

The last untargeted moments that we compare to the data are the returns that entrepreneurs receive from investing into their firm. This is important as a core prediction of our model is that poor entrepreneurs earn higher returns on average than wealthy entrepreneurs. We defer an in-depth discussion of this issue to Section 6.1, but we already point out here that this prediction of the model is indeed borne out by the data. We also demonstrate that the model matches the level of returns both unconditionally, and conditional on net worth. This is a success of our model, since our calibration strategy does not directly target these statistics.

5 Quantitative Analysis of Monetary Policy

We now analyze the response of the economy to an interest rate change. Our focus is on aggregate investment, in particular the investment response of entrepreneurs and how it depends on the wealth of entrepreneurs and its distribution.

The solid black lines in Figure 3.5 plot the response of the key aggregate variables to an expansionary monetary policy shock. Specifically, we consider an unexpected one time innovation of –100 basis points annually to the Taylor rule (3.8). Owing to the endogenous reaction of the central bank in our model, this leads to a drop in the liquid rate r^b on impact of about 36 basis points. Output, investment, consumption, labor, and inflation all rise in response to a cut in the interest rate. Output increases by about 1.4% on impact. This number is in line with—though at the upper end of—empirical estimates of the effects of monetary policy shocks (Christiano et al. 2005; Ramey 2016).[16] Total investment, in private firms as well as in the representative firm, rises by 4.1%.

Entrepreneurs, even though they only comprise a small fraction of the total population, are important for setting in motion the general equilibrium feedback loop between higher income and higher consumption demand that characterizes monetary transmission in HANK models. To see this, we first break down the aggregate output response on impact after the shock into its two most important components, aggregate consumption and investment. Table 3.8 shows that aggregate investment accounts for 56.5% of the overall increase in output while consumption makes up 26.5% (the remaining 17% are accounted for mostly by an increase in price adjustment costs). While entrepreneurs do not contribute significantly to the increase in consumption demand directly, they are responsible for about half of the total increase in investment. Two thirds of their additional investment is directed towards their private businesses, but entrepreneurs also account for about a quarter of the additional investment in the mutual fund and thus in capital employed by the representative firm. The expansion in entrepreneurial investment, in turn, leads to more labor demand and hence higher wages for workers, causing consumption demand to rise further.

Next, we consider two counterfactual scenarios. In both, we assume that entrepreneurs are ignorant about the evolution of a subset of aggregate variables. First, we solve for the

---

[16] Assuming that the output response is linear in the interest rate change, we can scale the impulse responses to an impact drop in the real liquid rate r^b of 100 basis points which would imply an increase in output of 3.9%.

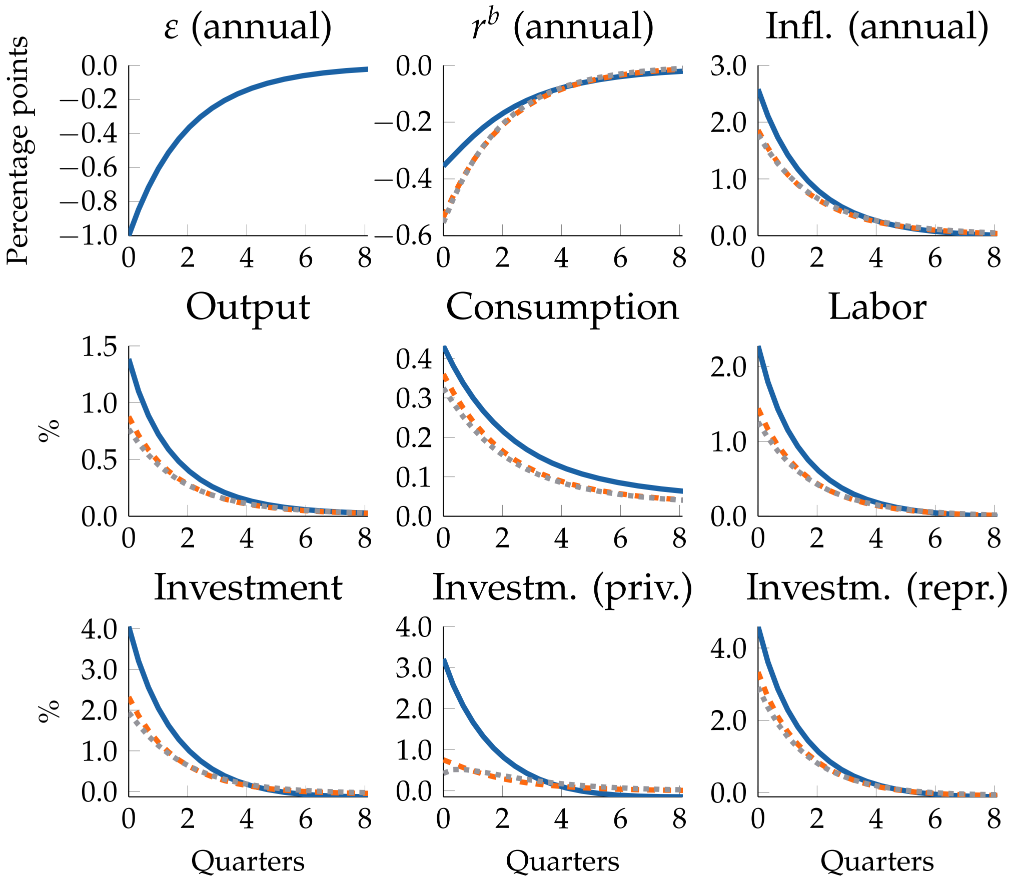


Figure 3.5: Response of aggregate variables to an expansionary monetary policy shock. *Notes:* Depicted are deviations from steady state values. The solid blue line shows the model's response to the shock. The dashed orange line shows the response when entrepreneurs (but not workers) are ignorant about changes in all aggregate variables. The dotted gray line shows the response when entrepreneurs are ignorant only about the change in the liquid rate r^b.

Table 3.8: Absolute change in consumption and investment relative to absolute output change (on impact), in %.

	Cons.	Inv. (total)	Inv. (priv.)	Inv. (repr.)
Total	26.5	56.5	17.5	38.9
Workers	24.6	29.5	-	29.5
Entrepreneurs	1.9	26.9	17.5	9.4

dynamics after the monetary policy shock when entrepreneurs do not take into account changes in any of the aggregate variables induced by the shock. We assume that they believe that aggregates are at their steady state values at all times and that they make their consumption and investment decisions accordingly. Importantly, entrepreneurs' assets still evolve according to actual prices. This implies that entrepreneurs still face income changes due to the monetary policy shock and all factor markets clear at all times. In the second case, we assume that entrepreneurs take into account changes in all aggregate variables except for the liquid interest rate r^b, about which they believe that it is constant at its steady state value at all times.[17] This allows us to assess the importance of the direct effect of monetary policy on entrepreneurs for the economy's response.

The orange lines in Figure 3.5 correspond to the first scenario in which entrepreneurs are ignorant about all aggregate variables. In this case, the aggregate dynamics following the monetary policy shock are significantly muted. The responses of output and investment to the interest rate change are only about half as large as in the baseline scenario. The investment response is dampened particularly strongly, which highlights again the importance of entrepreneurs for aggregate investment. If we rescaled the impulse responses to imply the same drop in the liquid rate r^b, these results would become even more pronounced. The dotted gray line shows the results for the second experiment, in which entrepreneurs take into account changes in all aggregate variables except that of the liquid rate r^b. The gray lines lie almost on top of the orange lines. Hence, the direct response of entrepreneurs to the change in the liquid interest rate is crucial for the transmission of monetary policy. To better understand its determinants, we next turn to the investment responses of entrepreneurs over the net worth distribution.

Heterogeneity among entrepreneurs Entrepreneurs as a group are important for the evolution of aggregate investment in response to the shock, but there is considerable heterogeneity within the group of entrepreneurs. Depending on the size of their firm and their net worth, entrepreneurs respond to the interest rate change very differently.

The solid blue line in Figure 3.6 depicts the total change in the entrepreneurs' private firm investment relative to their capital stock across the net worth distribution. We show the response on impact, immediately after the expansionary monetary policy shock hits the economy. The line exhibits an approximate u-shape. Relatively poor entrepreneurs respond strongly to monetary policy by expanding their investment. The response is smallest for entrepreneurs with a net worth of around \$3 million. For entrepreneurs with net worth above \$3 million, the response increases with net worth and then plateaus, so that wealthy entrepreneurs respond relatively strongly.

To understand what causes this heterogeneity, and guided by the decomposition of

---

[17] The aggregate variables that are relevant for the decisions of entrepreneurs are r^b, r^a, w, p, T, Y_e and Π. The first experiment holds entrepreneurs' believes about all of these constant at steady state values, the second experiment only holds believes about r^b constant.

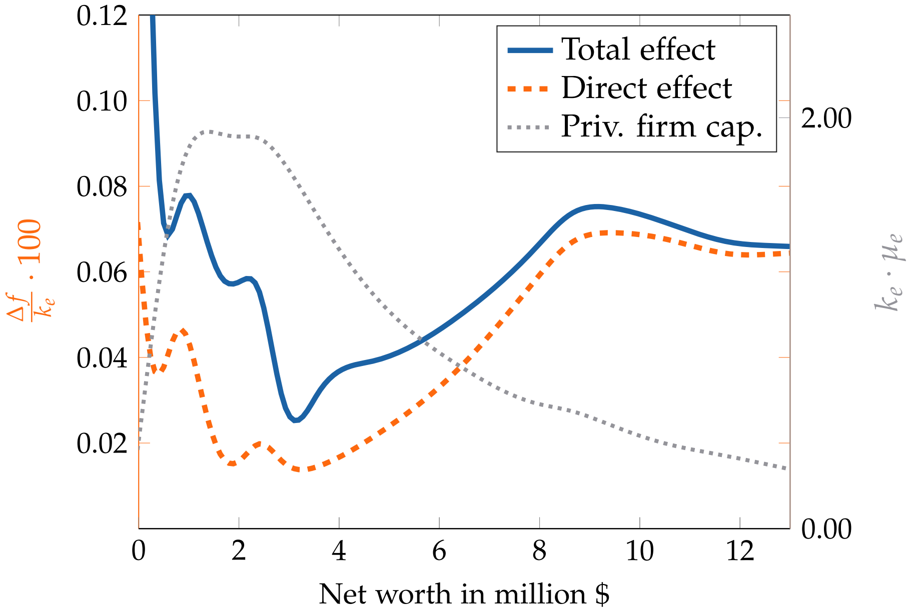


Figure 3.6: Heterogeneous private firm investment response after monetary policy shock. *Notes:* Blue solid line: Total change in private firm investment relative to private firm capital in response to monetary policy shock on impact (left y-axis). Orange dashed line: Change in firm investment caused by direct effect, i.e., only liquid rate changes, other prices held fix (left y-axis). Gray dotted line: Share of private firm capital $k_e \cdot \mu_e$ (right y-axis). All lines show averages within small bins of net worth.

the aggregate responses we performed in Figure 3.5, we follow Kaplan et al. (2018) and distinguish between direct and indirect effects of the interest rate change. Turning to the direct effects first, the orange dashed line in Figure 3.6 depicts the response of firm investment that is due solely to the interest rate change, keeping all other prices constant. We obtain it by asking how entrepreneurs respond if only the liquid interest rate r^b evolves as it does in Figure 3.5, while all other aggregate variables stay at their steady state levels.[18] The response is smaller than the general equilibrium effect, but the overall shape looks very similar. All firm owners invest more in their firm when the liquid rate r^b decreases and reduce their exposure to the now lower-yielding liquid bond.

Importantly, the magnitude of this reallocation effect varies greatly with the net worth of a firm's entrepreneur. For the poorest firm owners, at the very left border of the graph, investment elasticities are very large. These entrepreneurs take on debt to grow their firm, as the marginal return from their firm is very large. Once r^b is reduced, they experience a positive income effect as they have to pay lower interest rates on their debt, and they invest the additional income in their firm. In terms of aggregate investment, however, these entrepreneurs are of minor importance, as they hold a negligible share of the overall capital stock. This is illustrated by the gray dotted line, which plots the

---

[18] In contrast to the decomposition we performed in Figure 3.5, this is a partial equilibrium exercise. We simply ask how entrepreneurs would react to the interest rate path shown in Figure 3.5. We do not ask how prices would have to respond to support the resulting choices as equilibrium outcomes.

share of business capital held at respective points of the net worth distribution, $k_e \cdot \mu_e$.[19] A large number indicates that entrepreneurs at this level of net worth hold a large share of total private business capital.

Entrepreneurs with an intermediate amount of net worth do not rely on debt to finance the firm, but their firm still offers relatively high marginal returns. Put differently, the excess return of their firm investment over the riskless bond is large. When monetary policy changes r^b, this excess return is therefore not affected much in relative terms, and hence they rebalance their portfolio relatively little. Wealthy entrepreneurs who own large firms do not reap such high returns from their business. For them, the excess return over r^b is close to zero. Therefore, a change in r^b affects their excess return more significantly, and they reshuffle their portfolio much more than owners of smaller firms to implement the optimal combination of business risk and excess return over the risk-free rate.

Next, we turn to the indirect effects of the interest rate cut on entrepreneurial investment that work through changes in prices and income. The indirect effect on firm investment is the difference between the dashed and the solid line in Figure 3.6. It is the additional investment that is not due to the interest rate change itself. For most entrepreneurs, the indirect effects are smaller in magnitude than the direct effects. In particular, this is the case for wealthy entrepreneurs. To them the private firm is similar to any other asset in their portfolio. Therefore, they spend additional income almost proportionally on investment into the different assets and on consumption, and hence the indirect effect on private business investment is small. For entrepreneurs with little wealth, who own small firms, however, the indirect effects are large. These are households with highly profitable businesses who lack the resources to expand their firm. The rise in income induced by monetary policy allows them to grow their business, and they seize this opportunity.[20]

We summarize our results as follows. First, the investment decision of entrepreneurs significantly affects the aggregate output response. Second, investment of wealthy entrepreneurs responds more strongly than that of entrepreneurs in the middle of the wealth distribution due to a stronger portfolio reallocation effect. Decreasing returns to scale and idiosyncratic firm risk imply that wealthy entrepreneurs earn a low excess return over the risk-free rate. When the risk-free interest rate falls, they expand investment strongly to restore the optimal excess return. It is therefore crucial that our model produces a realistic distribution of excess returns over net worth. In the next section we look at data from the SCF to argue that it does. Third, poor entrepreneurs also respond strongly to monetary policy because of large indirect effects. However, by definition,

---

[19] The line integrates to the aggregate private firm capital stock $K_e = \int k_e \mu_e(i) di$. To obtain it, we average the private firm capital share within small bins of net worth.

[20] Corroborating these results, Figure 3.B6 in the appendix plots the marginal propensity to invest into the private business out of a transfer of \$500 into the liquid account as a function of net worth.

they only hold a small fraction of the total capital stock, which mutes their importance for aggregate investment.

6 Evidence for Model Implications

In this section we test two key implications of our model. The first is a negative relationship between business returns and net worth. The second is that wealthier entrepreneurs exhibit a stronger direct investment response to an interest change than poorer entrepreneurs. As in Section 2, we use data from the SCF.[21] We include households in the sample whose head is aged 25–65, and who have positive net worth and business wealth. As will become clear, valuations of businesses that are positive but very close to zero result in estimated returns that are very large. We therefore purge the sample of those households with the largest 5% of business returns, as defined momentarily.[22] We exclude the SCF wave of 1983 as the variables needed for computing the business returns are only available starting in 1989. Table 3.C7 in the appendix reports summary statistics for business returns, net worth and business wealth for the remaining sample.

6.1 Distribution of business returns over net worth

One implication of our quantitative model is that richer entrepreneurs receive smaller returns from their private businesses. To verify this implication in the data we need a measure of the business return. Following the baseline definition in De Nardi et al. (2007), we define it as the inverse price to earnings ratio

$$r_{it}^{e} = \frac{\text{business income}_{it}}{\text{business value}_{it}} .$$

Here, we index households by i, the year by t. Business income is the wage or salary income from the main job of the household's head plus business profits paid out to the household, all before taxes.[23] If the head's spouse works at the business we also add wage and salary income of the spouse. For the business value we rely on the answer of households to the question "What is the net worth of (your share of) this business?", i.e., we use the market value of the business.

Figure 3.7 shows the median business return in each decile of the net worth distribution of entrepreneurs for all SCF waves as well as for the most recent wave of 2019. The

---

[21] Wherever necessary, we deflate nominal values to 2019 US dollars using the CPI-U-RS (all items) series obtained from the Bureau of Labor Statistics.

[22] We consider different subsamples below, in particular, we look at the 2019 wave of the SCF and at all waves together. We drop the largest 5% over all waves when we consider all waves and the largest 5% in the 2019 wave when we consider the 2019 wave.

[23] By our definition of entrepreneurs, the head's main job is at the privately owned and managed business.

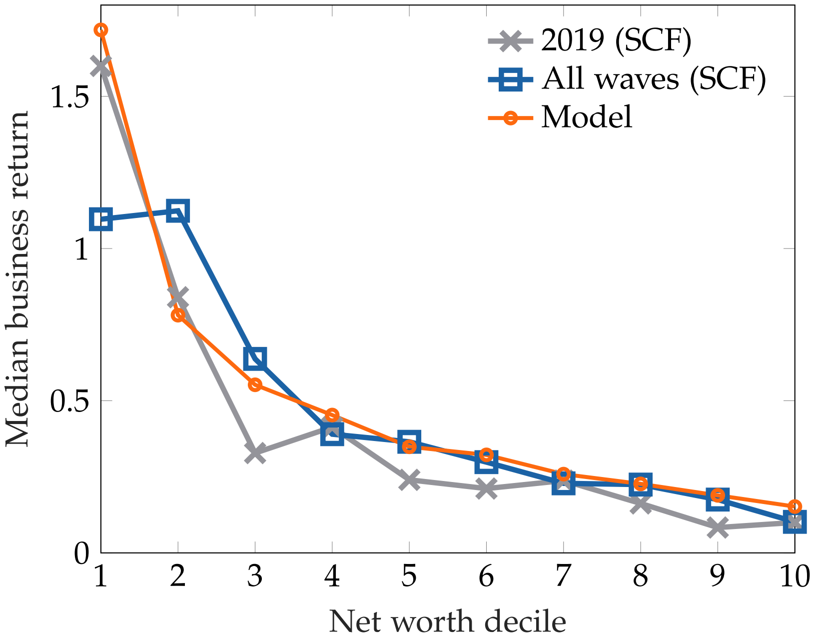


Figure 3.7: Median business returns by decile of the net worth distribution of entrepreneurs.
Notes: Depicted are returns from SCF data only for 2019 (gray), over all waves (blue), and steady state returns from our model (orange).

picture looks very similar for both samples. Returns are substantially lower in higher deciles of the net worth distribution than in lower deciles. Entrepreneurs in the first decile earn an annual return of 110% (all waves) and those in the highest decile of 10%.

The returns for entrepreneurs in the lower net worth deciles appear quite large. One explanation is that the value of their businesses is small and most of the return is actually labor income instead of capital income from their investment. We include wages of the entrepreneur in our definition of business income to be consistent with our model, in which we also do not distinguish between the part of entrepreneurial business income that comes from entrepreneurs' capital investment and the part that comes from their labor input. It is a defining characteristic of entrepreneurship that the two are difficult to distinguish. Lastly, all returns shown here correspond to business income before taxes, and hence returns after taxes would be smaller.

We also plot the implied median returns from our model steady state in Figure 3.7, and find that they fit the data very well, both in terms of levels and in terms of the evolution over net worth ($k_e + a + b$). We view this as a great success of our model to capture a relevant dimension of firm heterogeneity, as nothing in our calibration directly targets either the overall level of returns or the returns conditional on net worth deciles.

The negative relationship between wealth and returns to entrepreneurship we uncover is in line with recent empirical evidence provided in other studies. Xavier (2021) also uses SCF data, and finds that, within the asset class of private businesses, returns decline at the top of the wealth distribution. While we observe a largely monotone relationship in the data, she discovers an inverse u-shape, with returns largest in the 90th to

97th percentile of the population-wide net worth distribution.[24] The difference between her results and ours stem from the fact that she does not include the entrepreneurs' labor income in her measure of business profits, which leads to lower profits especially for smaller firms. In addition, Smith et al. (2021) document falling returns to private business capital among the highest percentiles of the wealth distribution using administrative income tax data. Boar et al. (2022) use balance sheet data on privately owned Spanish firms to document that private firm equity and returns are negatively correlated.[25] Given that firm equity and owner's net worth are highly positively correlated, we view this as further evidence in support of a negative relationship between entrepreneurs' net worth and business returns.

The results so far indicate a negative unconditional correlation between net worth and business returns. In Appendix C we study the relationship between these two variables in more detail. First, we estimate their relationship nonparametrically. Second, we estimate linear regressions in which we control for many observable household characteristics. In both cases, a robust negative relationship between net worth and returns emerges. We also discuss potential shortcomings of our analysis and investigate the relationship between business wealth and returns as well as that of business wealth and portfolio composition.

6.2 Portfolio response to monetary policy shocks

To empirically estimate how entrepreneurs adjust their portfolios in response to monetary policy, we would ideally observe a panel of entrepreneurial households, preferably at quarterly or even higher frequency, and trace their reaction to identified monetary policy shocks. Unfortunately, the SCF is neither a panel nor does it feature such high frequency, as the data is only collected every three years. We therefore follow an approach similar to Luetticke (2021) who faces the same challenges as we do.

First, for each wave of the SCF we estimate the portfolio share of firm capital, i.e., the ratio of business value to net worth, for each percentile p of the business return distribution. We denote the log of this portfolio share by $\gamma_{p,t}$, where t denotes the year of the SCF wave. We estimate these portfolio shares nonparametrically using local linear regressions, effectively using information about the portfolio shares in percentile p and in those percentiles that lie close to p to estimate $\gamma_{p,t}$. Appendix D lays out the details of this procedure.

We then use local projections in the spirit of Jordà (2005) to estimate the effect of monetary policy shocks on the estimated portfolio shares. Specifically, to estimate the effects of an interest rate movement at time t on portfolio shares at $t+h$, we use the

---

[24] In the 2019 SCF, the 90th percentile of the overall net worth distribution corresponds to the 64th percentile of the entrepreneurial net worth distribution, which we use when plotting Figure 3.7.

[25] See in particular Figure 1 in Boar et al. (2022).

regression

$$\gamma_{p,t+h} = \alpha + \beta_{p,h} \cdot FF_t + \delta_{p,h}^{Y} \cdot \ln(Y_{t-1}) + \delta_{p,h}^{FF} \cdot FF_{t-1} + u_{t+h}, \tag{3.9}$$

where α is a constant, FF denotes the Federal funds rate, Y is GDP, and u is an error term with $\mathbb{E}[u_t] = 0$. The estimate of interest is $\beta_{p,h}$ which captures the response of the log portfolio share in firm capital at horizon h to a 100 basis point increase in the interest rate at time t for the p-th percentile of the return distribution.

Since the federal funds rate is endogenous, we instrument it using a series of identified monetary policy shock, i.e., we estimate IV local projections. We use the narratively identified shock series, denoted ϵ_t^y, from Romer and Romer (2004) which was extended until 2007 by Ramey (2016). As the shock series ends in 2007, we only use SCF waves 1989 to 2007 in this section. In Appendix D we describe how we convert the monthly shock series into an annual series, and we also document our results when using the shock series from Gertler and Karadi (2015). They exploit high-frequency financial markets data to construct their shocks, which are available from 1990 to 2012.

The left panel of Figure 3.8 depicts our baseline estimates of $\hat{\beta}_{p,h}$ for $h = 0, 1, 2$. Consider the orange solid line first. It depicts the estimated portfolio response on impact to an exogenous 25 basis point cut in the interest rate for each percentile p of the return distribution. We order percentiles in decreasing order on the x-axis, as we have shown above that high returns typically correspond to the poorest entrepreneurs.

At most percentiles the response is positive, lending evidence to the portfolio reallocation channel that is also present in our model. In particular, the response is positive and statistically significant from zero for entrepreneurs at the median of the return distribution, depicted by the dashed line. In terms of magnitudes the estimates indicate that in response to the cut in the interest rate, the median entrepreneur increases her exposure to the firm by one to two percent in the first two years after the shock. While the blue solid line shows that the response after one year is similar to the one on impact, the gray line indicates that after two years the response is a bit smaller.

Turning to heterogeneity, entrepreneurs at both extremes of the return distribution react relatively strongly on impact and one year after the shock. Through the lens of our model, and in accordance with Figure 3.6, this could be interpreted as strong direct effects for entrepreneurs with large firms and small returns, and large responses of entrepreneurs with small firms and hence large returns. The u-shape, however, disappears in the second year after the shock. While our model does not imply a decline in the portfolio share after two years for firm owners with low returns (gray line), we would indeed expect the strongest reallocation towards firm capital right after the shock materializes, i.e., on impact and one year after the shock.

We obtain very similar results, when we consider residual portfolio shares after controlling for household characteristics, as shown in the right panel of Figure 3.8. In Appendix D, we describe this approach in greater detail and provide additional results.

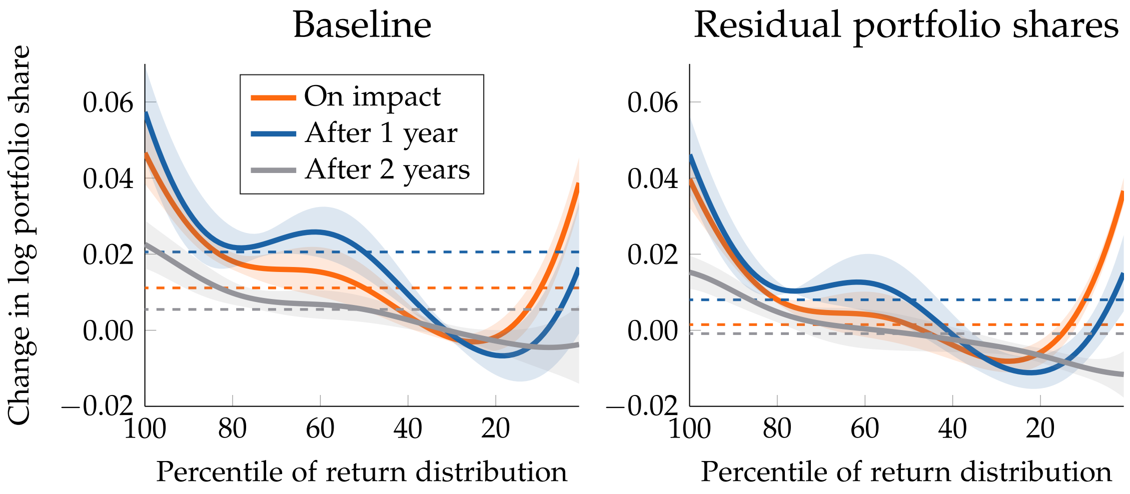


Figure 3.8: Impulse responses of portfolio shares to monetary policy shock.
Notes: Change in the logarithm of portfolio shares following a 25 basis points expansionary monetary policy shock by business return percentile. The dashed lines depict the responses at the median of the return distribution. Confidence bands are at the 66% level.

7 Consequences of Higher Wealth Inequality

The wealth distribution is endogenous in our model. To study how higher wealth inequality affects the transmission of monetary policy, we generally need to take a stance on the exogenous force that has raised wealth inequality to a new, higher level.

Before doing so, however, we follow a different approach in Subsection 7.1. In particular, we ask how changing the distribution affects the transmission of a cut in the interest rate, keeping all policy functions fixed at their steady state values. This allows us to stay silent on the drivers of increasing wealth inequality in recent decades. The results therefore apply to the effects of higher wealth inequality on monetary policy transmission regardless of the concrete source of elevated inequality. The disadvantage of the approach is that we can only study a static approximation to the general equilibrium response which lacks important dynamic elements, as we will discuss below.

In Subsection 7.2 we re-parameterize our model to generate a steady state with higher wealth inequality. Motivated by the decline in estate taxation in the US over the past decades, we achieve this by assuming that entrepreneurs are born with a positive amount of inherited wealth. We then compare the effects of monetary policy across the two model specifications, one with low and one with high inequality.

7.1 Fixed policy functions

We begin by approximating the general equilibrium response to a change in the interest rate. Let Y denote aggregate output, C aggregate consumption, I aggregate investment (both into capital of private firms and into capital of the representative firm), and G

government expenditures. In this section, we assume that

$$Y = C(Y, r^b) + I(Y, r^b) + G(Y, r^b). \tag{3.10}$$

For simplicity, we ignore parts of output here that are relatively small, in particular price, portfolio and capital adjustment as well as financial intermediation costs. Taking the total differential of (3.10), we have

$$\mathrm{d}Y = \left[\frac{\partial C}{\partial Y} + \frac{\partial I}{\partial Y} + \frac{\partial G}{\partial Y}\right] \mathrm{d}Y + \left[\frac{\partial C}{\partial r^b} + \frac{\partial I}{\partial r^b} + \frac{\partial G}{\partial r^b}\right] \mathrm{d}r^b \; .$$

Rearranging yields

$$\frac{\mathrm{d}Y}{\mathrm{d}r^b} = \frac{\frac{\partial(C+I+G)}{\partial r^b}}{1 - \frac{\partial(C+I+G)}{\partial Y}} = \frac{\frac{\partial(\int_i (c_i+d_i+f_i)\mu(i)\ \mathrm{d}i\ +G)}{\partial r^b}}{1 - \frac{\partial(\int_i (c_i+d_i+f_i)\mu(i)\ \mathrm{d}i\ +G)}{\partial Y}}\,, \tag{3.11}$$

where the last fraction expresses the aggregate effect in terms of individual households' optimal decision rules. Recall that we index the individual household by i, such that c_i is consumption of household i and $\mu(i)$ its mass. The term on the right-hand-side of (3.11) has an intuitive interpretation. The general equilibrium change in aggregate output upon a change in the interest rate is the direct effect of the interest rate change (the numerator) divided by one minus the marginal propensity to spend an additional dollar on consumption, investment, or government spending (the denominator). The goal of this section is to evaluate (3.11) once with the true steady state distribution, μ^{steady} and once with a distribution featuring higher wealth inequality, μ^{high}, holding the policy functions fixed.

Importantly, this approximation is static, only contemporaneous variables enter. Dynamic effects on today's household decisions, e.g., higher consumption today caused by looser borrowing constraints in the future due to elevated labor income, are shut off.

To calculate the denominator of (3.11), we need to make an assumption on how individual household income, which we denote by y_i, fluctuates with aggregate income. To this end, rewrite

$$\frac{\partial c_i}{\partial Y} = \frac{\partial c_i}{\partial y_i}\frac{\partial y_i}{\partial Y}$$

and analogously for investment. We assume that individual income fluctuates proportionally to aggregate income for all households, $\frac{\partial y_i}{\partial Y} = \frac{y_i}{Y}$. This simplification may not be innocuous since an unequal incidence of aggregate income movements may be an important amplification mechanism (Patterson 2022). It will be present in the next section, where disposable income responds to a monetary policy shock differently for different households.

Next, we approximate the marginal propensity to consume (MPC) $\frac{\partial c_i}{\partial y_i}$, the marginal

Table 3.9: Response to persistent decrease in the liquid interest rate r^b under steady state wealth distribution and distribution with higher inequality.

	Top 10% wealth share	$\frac{\mathrm{d}Y}{Y}$	$\frac{\partial(C+I+G)}{\partial r^b}\mathrm{d}r^b$	$\frac{\partial(C+I+G)}{\partial Y}$	$\frac{\partial I_e}{\partial r^b}\frac{\mathrm{d}r^b}{I_e}$
Steady state	81.5%	1.09%	.0102	.5024	2.49%
High inequality	82.5%	1.17%	.0116	.4978	2.84%
Relative change	1%	7%	13%	-1%	14%

propensity to invest (MPI) in private firm capital $\frac{\partial f_i}{\partial y_i}$, and the MPI in representative firm capital $\frac{\partial d_i}{\partial y_i}$ as the fraction of a \$500 transfer into the liquid account that households would spend on c, f and d respectively within one quarter. Kaplan et al. (2018) propose this approach to calculate MPCs. To compute $\frac{\partial G}{\partial Y}$, we assume that households finance government expenditures in proportion to their income. Given the proportional tax on labor and business income, this is a good approximation. Formally, we assume that $\frac{\partial G}{\partial Y} = \frac{\partial\left(\int_i g_i \,\mathrm{d}i\right)}{\partial Y}$ and that $\frac{\partial g_i}{\partial Y} = \frac{\partial g_i}{\partial y_i}\frac{\partial y_i}{\partial Y} = \frac{g_i}{y_i}\frac{y_i}{Y}$, where g_i corresponds to government spending financed by household i, i.e., taxes paid minus transfers received.

To quantify the numerator of (3.11) we need to know how households react to a change in the interest rate r^b holding income constant. This is the direct response to the monetary policy shock which we computed in Section 5 for private firm investment (see Figure 3.6). We exposed households to a change in the interest rate (depicted in Figure 3.5), keeping all other aggregate variables at their steady state levels. In the same way, we obtain the direct responses of consumption and other investment. From the government budget constraint we further know that $\frac{\partial G}{\partial r^b} = -B^S$.

The first row in Table 3.9 shows the results of the approximation (3.11) using the steady state distribution of households. The cut in the interest rate leads to an increase in output of 1.09%, which is a bit smaller than the response in Section 5 of 1.39%. This is not surprising, given that the approximation leaves out all *dynamic* general equilibrium forces affecting the households' decision. In the full dynamic general equilibrium, households realize that stimulated economic activity will lead to higher income for several quarters. Higher future income in turn results in even more aggregate demand (see Auclert et al. (2018) for a formal discussion of this point). Our static approximation abstracts from this dynamic effect.

To construct a wealth distribution with high inequality, μ^{high}, we proceed as follows. Guided by the empirical evidence in Section 2, we increase the wealth of the average entrepreneur relative to the average worker, and in doing so generate higher wealth inequality. To focus on the role of entrepreneurs most clearly, we leave the distribution of wealth among workers μ_w unaltered, and only change the distribution of wealth for entrepreneurs μ_e. In particular, we increase the size of each entrepreneur's private firm by 27%, which generates an increase in the overall top 10% wealth share by one percentage point. This is a relatively mild increase in wealth inequality. Figure 3.A4 in the appendix shows that the top 10% wealth share has gone up by about ten percentage points between the early 1980s and today. However, assuming the supply of labor in the economy remains unchanged, the employment share of private firms significantly increases, from 41% under the steady state distribution to 46% under the new distribution with larger private firms. We therefore view the considered experiment as a reasonable representation of the shift of wealth from workers to entrepreneurs that actually occurred in the US between 1980 and today.

The second column of Table 3.9 shows the core result of this section. Once we move to the distribution that features higher wealth inequality, the output response is strengthened, in our experiment by 0.08 percentage points. This represents an increase of 7% compared to the response implied by the original steady state distribution. Strikingly, as the relative changes in the last row reveal, the entire increase of the effects on real activity stem from the direct effect of monetary policy, i.e., from a change in the numerator of (3.11). The average marginal propensities to consume and invest in the economy (second to last column) are almost unaltered by the change in the wealth distribution.

There are two counteracting effects on the propensities to spend in the denominator of (3.11). Higher inequality leads to a smaller aggregate MPI because of a *within*-occupation effect. Small firm owners have higher propensities to invest additional income into their firms than large firm owners, and when more capital is in the hand of large firm owners, overall MPIs decline. Higher inequality leads to larger aggregate MPI, however, because of a *between*-occupation effect. The average entrepreneur features a higher MPI than the average worker, and in our experiment we increase the share of wealth held by the entrepreneurs. These two effects approximately cancel out in our calibration.

The larger effects under higher inequality can be explained with the mechanisms discussed in Section 5. A shift towards a distribution that features higher wealth inequality puts more wealth into the hands of entrepreneurs with a strong portfolio reallocation response. This can be seen in Figure 3.9, where the orange dashed line shows the direct effect of the change in the interest rate path, $\{r_t^b\}$, on firm investment (this is the same as in Figure 3.6). Under the new distribution with higher inequality, the distribution of firm capital is shifted to the right, and there are more entrepreneurs with large firms. Since these entrepreneurs exhibit a large elasticity of firm investment, monetary policy has stronger effects. In sum, the direct effect of the shock on aggregate private firm investment rises by 14% when moving from the low- to the high-inequality distribution, as the last column of Table 3.9 shows.

One caveat of the results so far is that wealth inequality within the group of entrepreneurs *declines* in our experiment. Wealth held by the richest ten percent of entrepreneurs relative to wealth held by all entrepreneurs decreases by about 2.5 percentage points. This stands in contrast to the data, which indicate that inequality among entrepreneurs has actually risen since the 1980s (see Figure 3.A5 in Appendix A). To

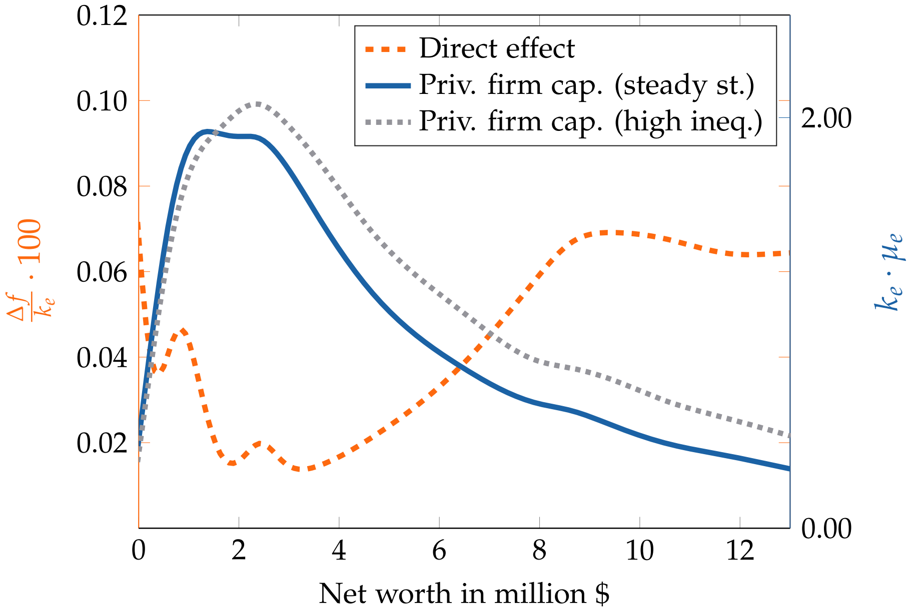


Figure 3.9: Direct effect and distributions of firm capital under low and high inequality.
Notes: Orange dashed line (left y-axis): Change in firm investment caused by direct effect, i.e., only by change in liquid interest rate r^b, other prices fixed. Blue solid line (right y-axis): Share of private firm capital $k_e \cdot \mu_e$ in steady state. Gray dotted line (right y-axis): Share of private firm capital $k_e \cdot \mu_e$ under counterfactual distribution with higher wealth inequality.

account for this, we consider a second high-inequality distribution μ^{high}. This time, instead of raising the firm size of all entrepreneurs by 27%, we only increase the firms of those entrepreneurs with the largest 10% of firms by 47% and leave all other firms unchanged. We choose 47% to generate an increase in the top 10% wealth share across all occupations of one percentage point, as before. This shift of wealth leads to an increase in inequality even among entrepreneurs: the top 10% share among entrepreneurs rises by about 2.5 percentage points. The output response in this case is 10% larger compared to the baseline scenario with μ^{steady}. The relatively stronger amplification compared to that shown in Table 3.9 is intuitive, as the shift of wealth towards the (high-elasticity) wealthy entrepreneurs is now even more pronounced than it was in the first experiment.

7.2 General equilibrium response under higher wealth inequality

We now compare the full general equilibrium dynamics following a monetary policy shock in our initial model to those in a version of the model with higher wealth inequality. The analysis shows that the results of the approximation in the previous subsection carry over when taking into account dynamic effects.

To increase wealth inequality, we assume that entrepreneurs are born with a positive amount of assets, unlike in the initial version of our model, in which all households were born with zero assets. This small change is enough to endogenously generate a higher degree of wealth inequality in the steady state. In principle, there are many ways to generate more wealth inequality. Here, we opt for one that involves only a small deviation from the original model. This makes it possible to most clearly attribute the differential responses under the new specification to higher wealth inequality. Alternatively, we could re-calibrate the model, targeting for instance a higher employment share in private firms. However, this would change all calibrated parameters, and it would be unclear which changes are driving our results.

The increase in initial wealth could be the result of lower progressivity of the US tax system, that has taken place since the 1980s (see Hubmer et al. 2021). Specifically, our experiment can be viewed as a decrease in estate taxation, leading to higher initial endowments of wealthy households' heirs. Indeed, federal estate taxation has become less broad-based since the 1980s. While 2.8% of the US adult population in 1982 had assets exceeding the exemption amount for estate taxation (assets worth more than \$325,000, or \$808,000 in 2016 terms), this fraction decreased to only 0.32% in 2016 (assets worth more than \$5,450,000). At the same time, the maximum marginal tax rate on these estates declined, from 70% in the early 1980s to 40% today.[26]

We implement this modification to our quantitative model as follows. Instead of assuming that entrepreneurs are born with zero wealth, they now own positive wealth $w' = \{b', a', {k_e}'\}$ at the beginning of their lives. Only entrepreneurs, not workers, are born with positive wealth in order to identify most clearly the effect of the shift in wealth towards private entrepreneurs that we observe in the data. For simplicity, we do not change household preferences: As before, households do not derive utility from leaving wealth to their offspring, so all bequests are accidental. The difference between the exercise conducted here and the one in the previous section is that now the steady state distribution, and with it all prices, endogenously adjust to the new environment.

We calibrate the amount of inherited wealth w' to \$590,000. This number leads to an increase in the top 10% wealth share by one percentage point relative to the baseline version of the model which makes our results here comparable to those in Section 7.1. The wealth endowment w' is composed entirely of private firm capital, $b' = a' = \$0$, but we found the composition to be inconsequential for the main results of this section. In the baseline model, assets of deceased households are distributed to living households in proportion to their assets, which effectively increases the return on assets. Now, only the assets of deceased households net of the wealth endowment of newborn households (bequests) are distributed to asset holders. This means the aggregate resource constraint continues to hold, since wealth of deceased households finances the initial endowments.

We expose the re-parameterized model to the same monetary policy shock as before. To be able to compare the responses under the two scenarios, we rescale them linearly to imply the same peak response of the interest rate r^b. Figure 3.10 plots the IRFs both for the economy with low and with high inequality. To make the differences between

---

[26] These numbers are provided by the Internal Revenue Service, in SOI Bulletin articles by Schwartz (1988), Jacobson et al. (2007), and Barnes (2021) and on the IRS website, accessed on Nov 29, 2020, at https://www.irs.gov/businesses/small-businesses-self-employed/whats-new-estate-and-gift-tax.

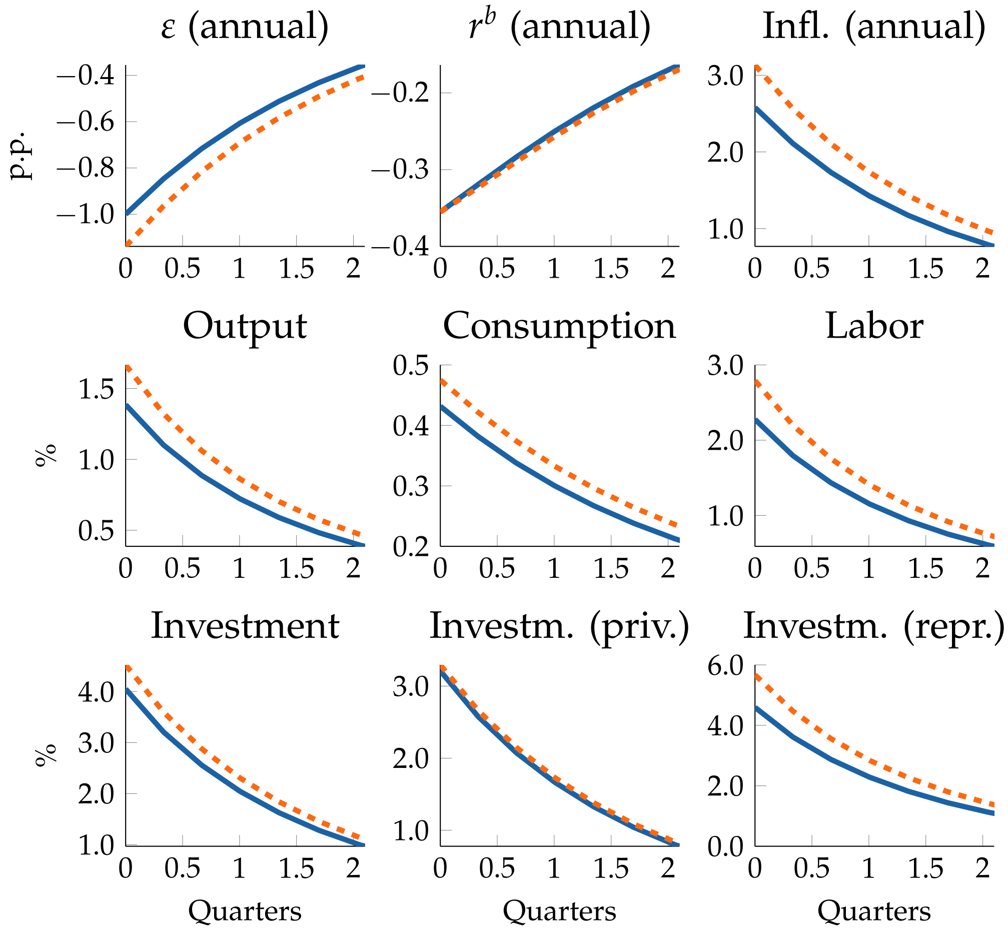


Figure 3.10: Response of aggregate variables to an expansionary monetary policy shock under low and high wealth inequality.

Notes: Depicted are deviations from steady state values. The solid blue line shows the response to the shock under the original steady state distribution. The dashed orange line shows the response when newborn entrepreneurs are born with positive wealth w', which leads to higher wealth inequality in steady state. All high-inequality responses are linearly rescaled to imply the same impact drop of r^b as under low inequality.

the two economies clearly visible, the figure only displays the responses for the first two quarters after the shock.

As in Section 7.1, higher wealth inequality amplifies the real effects of monetary policy. The output response goes up from 1.39% under low inequality to 1.67% under high inequality, i.e., the effects are magnified by about 20% of the initial response. This corroborates our previous finding that higher wealth inequality, by putting more wealth into the hands of wealthy entrepreneurs, strengthens the effects of monetary policy in general equilibrium.

At first sight, Figure 3.10 seems to indicate that private firm investment is not the most influential driver behind the stronger output effects, as its responses under high and low inequality are similar. To better understand the reasons for this, Figure 3.11 plots the distribution of firm capital in the initial steady state (blue solid line) and when entrepreneurs are born with positive bequests (gray dotted line), as well as the direct

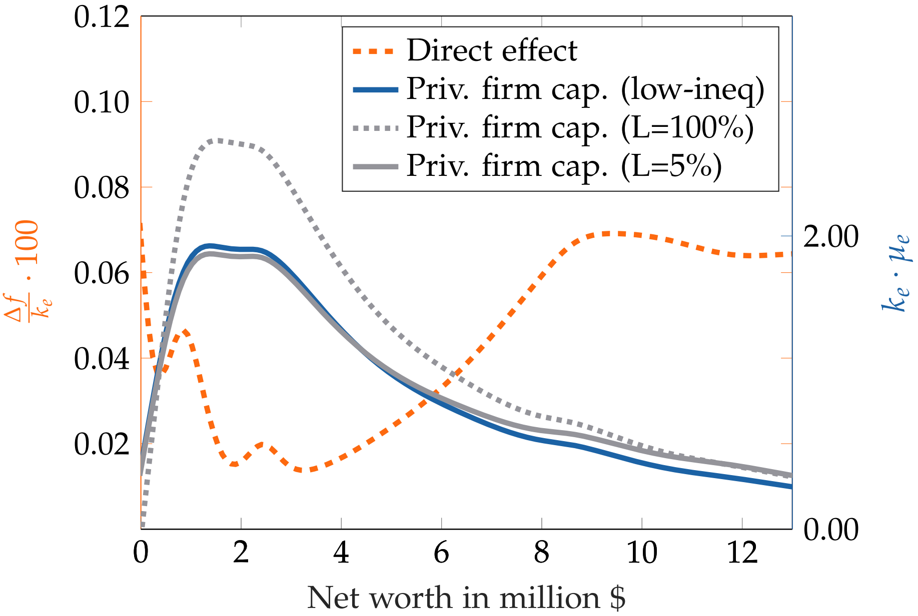


Figure 3.11: Direct effect and different private firm capital distributions.

Notes: Left y-axis: Change in firm investment caused by direct effect, i.e., only by change in r^b (evaluated in the initial steady state) (orange dashed). Right y-axis: Share of private firm capital $k_e \cdot \mu_e$. Blue solid: initial steady state distribution; gray dotted: high-inequality distribution when all entrepreneurs receive bequests; gray solid: high-inequality distribution when $L = 5\%$ of entrepreneurs receive bequests.

effect on firm investment in the initial steady state. While the considered experiment does increase the share of firm capital held by rich entrepreneurs with large direct effects, it increases to an even bigger extent the amount of firm capital held by medium-wealthy entrepreneurs with small investment elasticities.

Why do we still obtain larger responses of aggregate investment and output under high than under low inequality? To develop an answer, consider Table 3.10. The first row captures the initial (low-inequality) steady state of our model. Here, entrepreneurs do not receive bequests and the share of workers employed in the private firms is 41%. The second row corresponds to the high inequality steady state, in which all newborn entrepreneurs receive bequests of $590,000. The share of labor employed in the private firms rises to 48% and the initial output response to the monetary policy shock gets amplified by 20% as shown in Figure 3.10.

The last three columns split the direct effect of the interest rate change on impact by type of investment: total investment, private firm investment and representative firm investment. To obtain these numbers we compute the reaction of all households in the economy to the path of the interest rate $\{r_t^b\}$ depicted in Figure 3.5, just like in Section 5. The direct effect on private firm investment (second to last column) is indeed smaller under high inequality (second row) than under low inequality (first row), as Figure 3.11 suggested. Total investment still responds more strongly, however, since in the new steady state a larger share of it goes into private firm capital. Since private firm investment features a higher elasticity than investment into the representative firm, the

Table 3.10: Responses to interest rate changes under different bequest regimes.

(1) L	(2) Bequest size ($m)	(3) Y response increase	(4) Labor at entre.	(5) Top 10% wealth share	(6) Direct effect on inv. $\frac{\partial I}{\partial r^b}\frac{\mathrm{d}r^b}{I}$	(7) $\frac{\partial I_e}{\partial r^b}\frac{\mathrm{d}r^b}{I_e}$	(8) $\frac{\partial I_r}{\partial r^b}\frac{\mathrm{d}r^b}{I_r}$
0%	—	—-	41%	81.5%	1.42%	2.49%	0.73%
100%	0.59	20%	48%	82.5%	1.53%	2.40%	0.72%
50%	1.18	12%	46%	82.9%	1.48%	2.37%	0.71%
10%	5.89	8%	43%	83.3%	1.48%	2.52%	0.71%
5%	11.79	5%	42%	83.1%	1.47%	2.53%	0.72%

Notes: The first row represents the initial steady state, the second to last rows vary the bequests received by entrepreneurs. Column (1) shows the fraction of entrepreneurs who receive bequests. Column (2) shows the bequeathed amount per bequest in $ million. Column (3) shows by how much the impact output response increases compared to the baseline. Column (4) indicates the fraction of workers employed in the private firms in steady state, column (5) the top 10% wealth share. The last three columns correspond to the impact change in total investment (6), in private firm investment (7) and in investment into the representative firm (8) that is due to the direct effect, i.e., when all prices are at their steady state level and only $\{r_t^b\}$ evolves as in Figure 3.5.

direct effect on total investment becomes larger. This in turn causes incomes to rise more strongly under high inequality, thereby inducing second-round (indirect) effects that in sum lead to the larger output response shown in Figure 3.10.

The result that the direct effect on private firm investment *decreases* under high inequality, contrary to the experiment in Subsection 7.1, is sensitive to the precise implementation of the change in estate taxation. Suppose only a "lucky" fraction L of entrepreneurs receives bequests, and the fraction $1 - L$ is born with zero assets as in the initial steady state. The total amount of bequests is the same as before, $590,000 per entrepreneur. Hence, when the share of lucky entrepreneurs is higher, bequests are more concentrated. Fewer entrepreneurs receive bequests, but for those who do the bequest is larger.

A graphical illustration of the steady state firm capital distribution with $L = 5\%$ is depicted in Figure 3.11 (gray solid line). The difference compared to the initial distribution in this case is smaller than when $L = 100\%$. The reason is that when $L = 5\%$, the few entrepreneurs who are lucky recipients of bequests diversify the wealth they inherit across the three assets relatively quickly, and therefore the increase in aggregate private firm capital compared to the baseline is limited. In contrast, when $L = 100\%$ the individual bequests are much smaller and because returns on private firm capital are high for small firms, newborn entrepreneurs leave the inherited wealth predominantly in firm capital. Figure 3.11 also shows that, in contrast to the case where we assumed bequests for all entrepreneurs, when $L = 5\%$ only the right tail of the firm capital distribution becomes notably fatter, indicating the presence of a larger share of entrepreneurs with a strong direct investment response to interest rate changes.

When all newborn entrepreneurs receive bequests, the top 10% share within the group of entrepreneurs decreases compared to the initial steady state. This is at odds with the empirical observation that wealth inequality among entrepreneurs has increased over time. In contrast, inequality among entrepreneurs stays nearly unchanged when only very few of them receive bequests. Hence, the latter case is relatively more in line with the empirical evidence than the former.

The last three columns of Table 3.10 reflect the observations in Figure 3.11. The fraction of workers employed in private firms falls as L decreases, because the higher the bequests the more newborn entrepreneurs invest the inherited wealth in a diversified portfolio. The direct effect of private firm investment increases relative to the initial specification when only a small fraction of entrepreneurs is born wealthy, because the share of high-elasticity entrepreneurs grows. In sum, the output response is larger in all experiments under higher inequality. When rescaled to imply an increase in the overall top 10% wealth share of one percentage point, the magnitude of amplification varies between 3% and 20%.

8 Conclusion

Entrepreneurs constitute a small fraction of all households, but they hold a large share of total wealth, and their firms employ almost half of the workforce. In addition, the gap between average wealth held by entrepreneurs and by workers has increased over the recent decades. We documented these facts using survey data from the SCF. Together with a well-studied rise in wealth inequality in the US since the 1980s, these observations motivated our research questions: How important are entrepreneurs for the transmission of monetary policy to the real economy? How does the observed shift in wealth towards entrepreneurs affect the transmission of monetary policy?

We built a HANK model with entrepreneurs to provide answers to these questions. Upon a cut in the interest rate on liquid assets, entrepreneurs increase the portfolio share of their private firms. The strength of this portfolio reallocation effect is heterogeneous across the net worth distribution. Wealthy entrepreneurs own large firms and earn business returns that are only slightly above the risk-free rate, both in our model and in the data. Monetary policy that changes the risk-free rate therefore affects their excess return significantly in relative terms. Hence, wealthy entrepreneurs rebalance their portfolio more strongly than entrepreneurs with low net worth, whose excess returns are high and therefore affected relatively little by a change in the interest rate. We presented empirical evidence that two key implications of our model, decreasing business returns in net worth and a heterogeneous portfolio reallocation effect, are supported by the data.

In our model, entrepreneurs are quantitatively important for the impact of monetary policy on the real economy. If entrepreneurs do not respond to changes in prices and aggregate quantities, the output response to an interest rate cut is approximately 50%

smaller. Moreover, our model implies that an increase in the top 10% wealth share by one percentage point—a mild increase in wealth inequality—amplifies the aggregate output response by 3 to 20%.

Additional aspects of entrepreneurial investment could be important for the transmission of monetary policy. We focused on the intensive margin of entrepreneurial investment and did not model entry and exit from entrepreneurship, which might vary over the business cycle and respond to monetary policy (see Levine and Rubinstein 2020, and references therein). We also did not allow for collateralized borrowing or financing through outside equity. Although the predominant share of entrepreneurs relies on their own funds to finance their firm, outside financing might be an important dimension to study in future work.

Appendix A More Data on Entrepreneurs and Wealth Inequality

Aggregate statistics This subsection provides additional empirical evidence on entrepreneurial households and their firms. Figure 3.A1 plots the share of households that we classify as entrepreneurs over time. Figure 3.A3 plots average employment per entrepreneurial firm. Figure 3.A2 displays the share of total household wealth held by entrepreneurs. It shows that over the recent decades, entrepreneurs hold on average a third of wealth in the economy. Furthermore, the same upward time trend that was visible in the plots of the main text is visible here as well. One might be worried that this result is driven exclusively by the data point in 1983 with a very low entrepreneurial wealth share. However, even without the observation in 1983, the time trend is positive and statistically significant with a p-value of 1.5%.

Figure 3.3 in the main text documents the share of total employment accounted for by entrepreneurial firms. The share is large (on average 46%) and growing over time. Since we lack information on the intensive margin of labor supplied in the entrepreneurial firms, one might be worried that the share of total hours worked is much lower because private firms might be more likely to employ people on a part-time basis. To address this concern to some extent, we compare the distribution of private businesses over industries with a lot of part-time work. However, there is little indication that private firms are overrepresented in industries with many part-time employees. According to the Bureau of Labor Statistics (BLS), in January 2019, about 17% of all US workers worked part-time, the large majority of them (13%) for non-economic reasons. More than 50% of the wage and salary workers working part-time for non-economic reasons worked in retail trade, food services and drinking places, and private educational services.[27] While data on industries of entrepreneurs' firms in the more recent waves of the SCF is too coarse to be informative, data on industries before 1992 can provide some insight. In 1992, the four industries entrepreneurs mentioned most often as the industry of their first firm were (see also Table 3.A5)

- Professional practice, incl. law, medicine, architecture; accounting; bookkeeping (17%)
- Contracting; construction services; plastering; painting; plumbing (14%)
- Retail and/or wholesale business excluding restaurants, bars, direct sales (e.g., Tupperware), gas stations, and food and liquor stores (10%)
- Farm; nursery; train dogs; forest management; agricultural services; landscaping; fisheries (9%)

---

[27] https://www.bls.gov/opub/mlr/2018/article/who-chooses-part-time-work-and-why.htm, accessed on Nov 7, 2021.

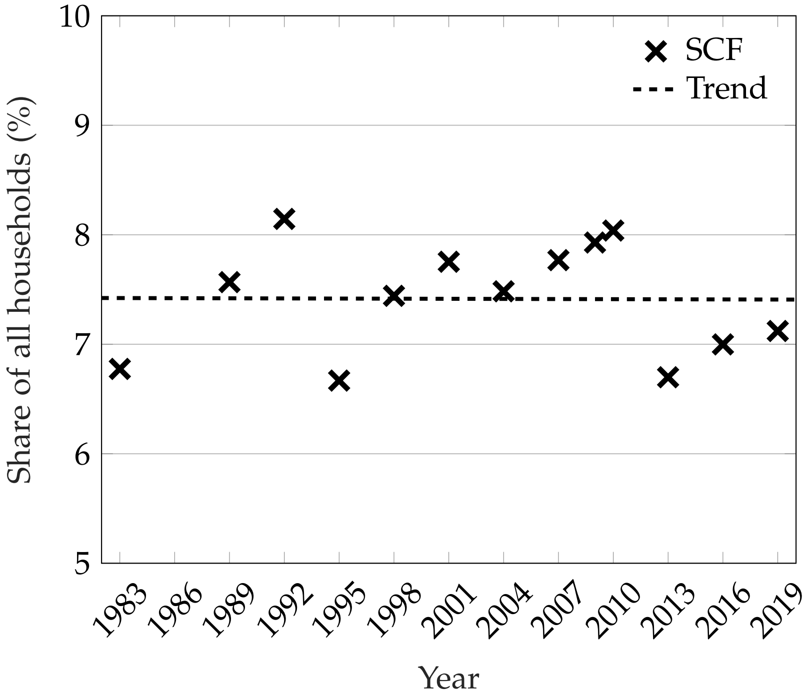


Figure 3.A1: Entrepreneurs as a share of all households, 1983–2019.

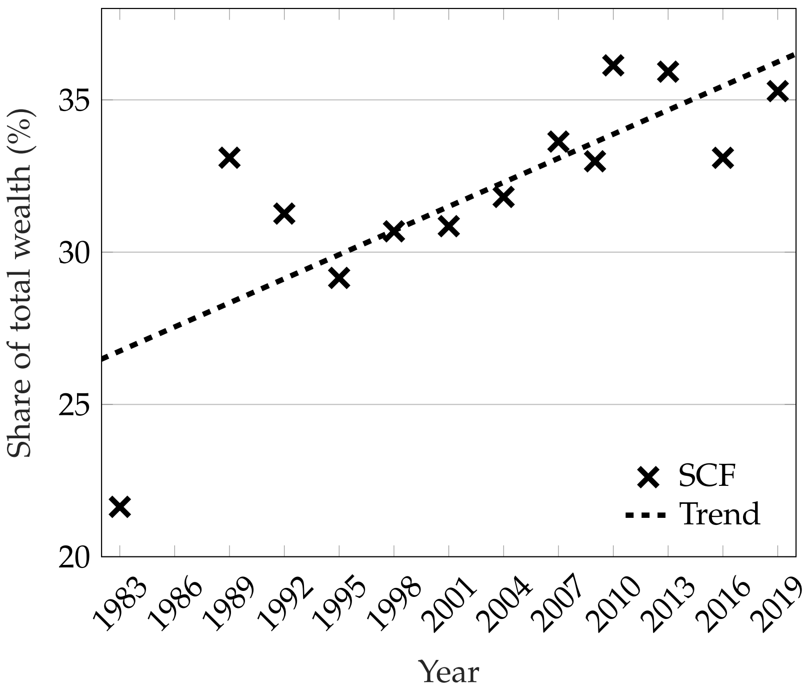


Figure 3.A2: Share of total US household wealth held by entrepreneurs, 1983–2019.

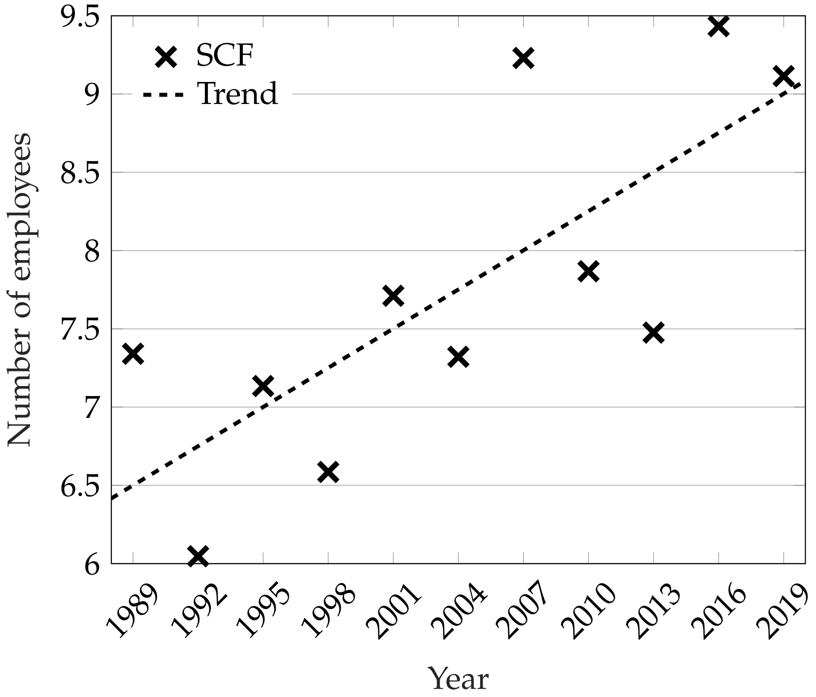


Figure 3.A3: Average number of employees in firms owned by entrepreneurs, 1989–2019.

Table 3.A1: Firm size distribution by employment (SCF 2019)

Employees	Share of firms (in %)	Share of employment (in %)
1 (Micro)	39.3	4.7
2–9 (Micro)	50.2	20.0
10–49 (Small)	7.9	17.9
50–249 (Med.)	2.2	24.2
250 and more	0.4	33.2

Notes: Since we observe employment and ownership shares only in the first two businesses of a given entrepreneurial household, we assume that if an entrepreneur has more than two businesses employment in these additional businesses are as in the second business.

Hence the overlap between those industries with many private businesses and those with a lot of part-time work appears to be small.

Firm size distribution Table 3.A1 documents the firm size distribution in 2019 by employment. The distribution is highly skewed: A large fraction of firms is very small in terms of employment, and only few are very large. However, as can be seen in the second column of the table, the few large firms are important for the overall employment of entrepreneurial sector. More than three quarters of all employment in private businesses is due to firms that employ ten or more workers. A similar pattern can be seen in Table 3.A2, which reports the firm size distribution in terms of gross sales. Lastly, Tables 3.A3, 3.A4 and 3.A5 show the distribution of entrepreneurial firms across different legal statuses, sources of funding and industry respectively.

Table 3.A2: Firm size distribution by gross sales (SCF 2019)

Sales (in $ m)	Share of firms (in %)	Share of sales (in %)
< 2 (Micro)	93.0	14.2
2–10 (Small)	5.1	11.8
10–50 (Med.)	1.4	14.7
50 and more	0.5	59.3

Notes: Since we observe gross sales and ownership shares only in the first two businesses of a given entrepreneurial household, we assume that if an entrepreneur has more than two businesses gross sales in these additional businesses are as in the second business.

Table 3.A3: Firms by legal status (SCF 2019)

Legal status	Share (in %)	Share of net worth (in %)
Partnership	5.9	6.6
Sole Proprietorship	40.8	13.5
S Corp.	14.1	25.8
Other Corp. (incl. C Corp.)	7.1	9.8
Limited Partnership / LLP	32.1	44.3

Notes: Left column: Share of entrepreneurs who declare that their first business is of a given legal status. Right column: Net worth of entrepreneurs who declare that their first business is of a given legal status, relative to total entrepreneurial net worth.

Table 3.A4: Firms by source of funding (SCF 2019)

Source of funding	Share (in %)	Share of net worth (in %)
Personal savings	26.3	14.6
Credit card	8.5	6.3
Personal loan	6.7	6.7
Business loan	10.7	16.2
Equity investors	1.1	2.0
Inherited	0.0	0.0
No external money	53.4	54.7
No answer	1.7	9.0

Notes: Multiple answers possible. Left column: Share of entrepreneurs who declare that they used a given source of funding for their first business. Right column: Net worth of entrepreneurs who declare that they used a given source of funding for their first business, relative to total entrepreneurial net worth.

Table 3.A5: Firms by industry (SCF 1992, seven most important by share)

Industry	Share (in %)	Share of NW (in %)
Professional practice, incl. law, medicine, architecture, accounting, bookkeeping	16.8	19.7
Contracting; construction services; plastering; painting; plumbing	13.8	9.4
Other retail and/or wholesale business	9.9	10.7
Farm; nursery; train dogs; forest managem.; agricultural services; landscaping; fisheries	9.4	7.0
Real estate; insurance	7.3	15.8
Manufacturing, incl. printing/publishing	6.6	11.1
Personal services: hotel, dry cleaners, funeral home	6.3	2.9

Notes: Left column: Share of entrepreneurs who declare that their first business is in a given industry. Right column: Net worth of entrepreneurs who declare that their first business is in a given industry, relative to total entrepreneurial net worth.

Wealth inequality As pointed out in the main text, several studies have found that wealth inequality has been rising in the US since the 1980s (Kuhn et al. 2020; Saez and Zucman 2016; Hubmer et al. 2021). Figure 3.A4 shows this using the share of wealth held by the richest 10% of the population as a measure of wealth inequality. Moreover, wealth inequality has also increased within the group of entrepreneurs, as Figure 3.A5 shows.

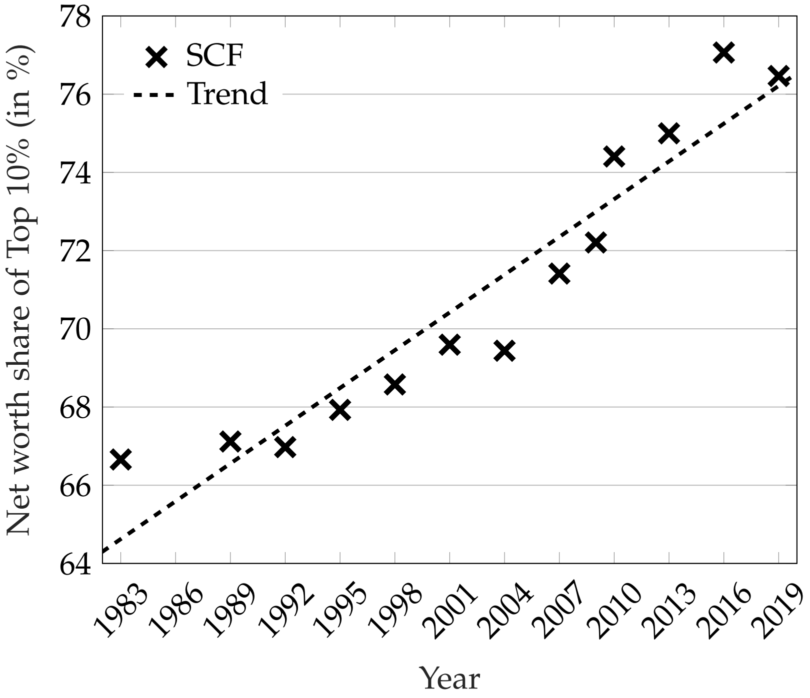


Figure 3.A4: Share of total wealth held by the wealthiest 10% of households.

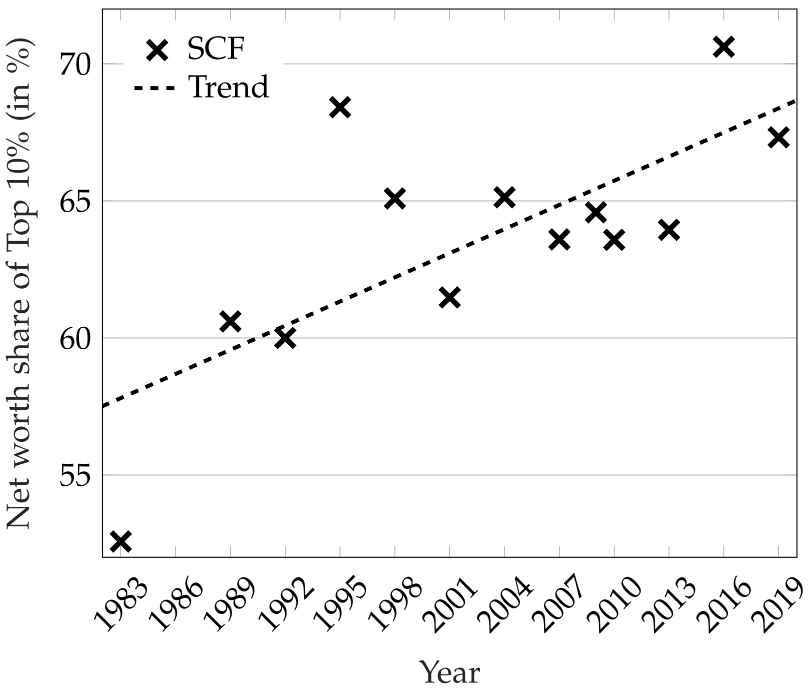


Figure 3.A5: Wealth of richest 10% of entrepreneurs relative to wealth of all entrepreneurs.

Appendix B Model Details and Derivations

B.1 Equilibrium

An equilibrium consists of paths for individual household decisions $\{a_t, k_{et}, b_t, c_t, d_t, \ell_t, f_t, n_{et}\}_{t\geq 0}$, input prices $\{r_t^k, w_t\}_{t\geq 0}$, returns on liquid and illiquid assets $\{r_t^b, r_t^a\}_{t\geq 0}$, the share price $\{q_t\}_{t\geq 0}$, the intermediate good price $\{p_t\}_{t\geq 0}$, the inflation rate $\{\pi_t\}_{t\geq 0}$, fiscal variables $\{T_t\}_{t\geq 0}$, τ_l, τ_e, G, B^S, distributions $\{\mu_{wt}, \mu_{et}\}_{t\geq 0}$, and aggregate quantities such that, at every t:

1. Given equilibrium prices, taxes, and transfers, household decisions of workers and entrepreneurs solve the problems (3.2) and (3.3).
2. Firms maximize profits.
3. The path of distributions satisfies aggregate consistency conditions.
4. The bond market and the capital market clear, the labor market clears, and all goods markets clear.
5. Monetary policy follows the Taylor rule (3.8), the government budget is balanced (3.7).

Bond market clearing Households demand liquid bonds

$$B_t^D = (1 - s_e) \int b_t \, \mathrm{d}\mu_{wt} + s_e \int b_t \, \mathrm{d}\mu_{et}$$

and the bond market clears if $B^S = B_t^D$.

Capital market clearing The representative firm optimally demands K_{pt}. Total supply of the illiquid asset by the households is

$$A_t^S = (1 - s_e) \int a_t \, \mathrm{d}\mu_{wt} + s_e \int a_t \, \mathrm{d}\mu_{et}$$

and the capital market clears if $K_{pt} = A_t^S - q_t$.

Labor market clearing Aggregate labor supply is

$$N_t^S = (1 - s_e) \int \exp(z) \cdot \ell_t \, \mathrm{d}\mu_{wt}.$$

Labor demand is the sum of demand by the publicly traded firm and demand by entrepreneurial firms

$$N_t^D = N_{pt} + N_{et} = N_{pt} + s_e \int n_{et} \, \mathrm{d}\mu_{et}$$

and the labor market clears if $N_t^D = N_t^S$.

Input goods market clearing We have that

$$\int_0^1 Y_t(j)\mathrm{d}j = Y_{pt} + s_e \int y_e \mathrm{d}\mu_{et}.$$

Intermediate goods market clearing We have that

$$Y_t = \int_0^1 Y_t(j)\mathrm{d}j$$

and by symmetry of all intermediate goods firms,

$$Y_t(j) = Y_t \quad \forall j$$

Once the markets for the inputs and the intermediate goods clear, market clearing for the final good follows from Walras' law.

Entrepreneurial taxes Revenues from taxing entrepreneurs that show up in the government budget constraint (3.7) are defined as

$$\mathrm{Rev}_t = s_e \tau_e \int \left(\Pi_e - \delta k_{et}\right) \, \mathrm{d}\mu_{et}.$$

B.2 Hamilton-Jacobi-Bellman equation

If labor productivity and entrepreneurial talent follow the jump-drift processes described in Section 4, the solution to the entrepreneurs' problem can be characterized recursively by the following Hamilton-Jacobi-Bellman equation for low-productivity types (y_l)

$$\begin{aligned}
(\rho + \zeta)\, V(b,a,k_e,y_l) = \max_{c,d,f} & \, u(c,\bar{\ell}) \\
& + V_b(b,a,k_e,y_l)\big[(1-\tau_e)\Pi_e(k_e,y_l) + r^b(b)b + T - d - \chi^a(d,a) \\
& \qquad - f - \chi^e(f,k_e) + \tau_e \delta k_e - c\big] \\
& + V_a(b,a,k_e,y_l)(r^a a + d) + V_k(b,a,k_e,y_l)(f - \delta k_e) \\
& + \frac{1}{2} k_e \sigma_k^2 V_{kk}(b,a,k_e,y_l) \\
& + \lambda_{y,lh}(V(b,a,k_e,y_h) - V(b,a,k_e,y_l))
\end{aligned} \tag{3.12}$$

and analogously for $V(b,a,k_e,y_h)$, i.e., high productivity types.

The solution to the workers' problem is characterized by

$$
\begin{aligned}
(\rho+\zeta)\, V(b,a,z) = & \max_{c,\ell,d} u(c,\ell) \\
& + V_b(b,a,z)\left[(1-\tau) w \exp(z)\ell + r^b(b)b + T - d - \chi^a(d,a) - c\right] \\
& + V_a(b,a,z)(r^a a + d) \\
& + \sum_{j\in\{1,2\}} V_{z_j}(b,a,z)(-\beta_j z_j) + \lambda_j \int_{-\infty}^{\infty} (V(b,a,x) - V(b,a,z_j))\phi_j(x)\mathrm{d}x
\end{aligned} \tag{3.13}
$$

where $\phi_j(x)$ denotes the pdf of a normal distribution with standard deviation σ_{zj}.

B.3 Derivation of Phillips Curve

Here we derive the New Keynesian Phillips curve following Appendix B.2 of Kaplan et al. (2018). Equivalently to 3.4, we can formulate the profit maximization problem as a choice over firm level inflation π_{jt},

$$
\begin{aligned}
& \max_{\{\pi_{jt}\}_{t\geq 0}} \int_{t=0}^{\infty} e^{-\int_0^t r_s^a \mathrm{d}s} \left[\left(\frac{P_t(j)}{P_t} - mc_t\right)\cdot Y^d\left(\frac{P_t(j)}{P_t}\right) - \Theta\left(\pi_{jt}\right)\right]\mathrm{d}t \\
& \text{s.t.} \quad \dot{P}_t(j) = \pi_{jt} P_t(j)
\end{aligned}
$$

A necessary condition for optimality is the associated HJB equation

$$
\begin{aligned}
r_t^a J(t, P_t(j)) = \max_{\pi_{jt}} & \left(\frac{P_t(j)}{P_t}\right)^{1-\epsilon} Y_t - mc_t \left(\frac{P_t(j)}{P_t}\right)^{-\epsilon} Y_t - \frac{\theta}{2}\pi_{jt}^2 Y_t \\
& + J_t(t, P_t(j)) + P_t(j)\pi_{jt} J_p(t, P_t(j)),
\end{aligned} \tag{3.14}
$$

where π_{jt} is the firm-specific inflation rate $\pi_{jt} = \frac{\dot{P}_t(j)}{P_t(j)}$. The first order condition for the maximization problem in (3.14) is

$$
J_p(t, P_t(j)) = \frac{\theta \pi_{jt} Y_t}{P_t(j)}, \tag{3.15}
$$

the envelope condition is

$$
\begin{aligned}
(r_t^a - \pi_{jt}) J_p(t, P_t(j)) = & \frac{Y_t}{P_t}(1-\epsilon)\left(\frac{P_t(j)}{P_t}\right)^{-\epsilon} + \frac{Y_t}{P_t}\epsilon \cdot mc_t \left(\frac{P_t(j)}{P_t}\right)^{-\epsilon-1} \\
& + J_{tp}(t, P_t(j)) + P_t(j)\pi_{jt} J_{pp}(t, P_t(j)) \,.
\end{aligned}
$$

Since firms are symmetric, $P_t(j) = P_t$ and $\pi_{jt} = \pi_t$, and we have

$$(r_t^a - \pi_t)J_p(t, P_t) = (1-\epsilon)\frac{Y_t}{P_t} + \epsilon \cdot mc_t \frac{Y_t}{P_t} + J_{tp}(t, P_t) + \pi_t P_t J_{pp}(t, P_t). \tag{3.16}$$

Taking the derivative of (3.15) with respect to time gives

$$J_{pp}(t, P_t(j))\dot{P}_t(j) + J_{tp}(t, P_t(j)) = \frac{\theta \dot{\pi}_t Y_t}{P_t(j)} + \frac{\theta \pi_t \dot{Y}_t}{P_t(j)} - \frac{\theta \pi_t Y_t}{P_t(j)} \frac{\dot{P}_t(j)}{P_t(j)}.$$

Recall that $\pi_t P_t = \dot{P}_t$ and substitute the above expression into (3.16). This gives the New Keynesian Phillips curve (3.5)

$$\left(r_t^a - \frac{\dot{Y}_t}{Y_t}\right)\pi_t = \frac{\epsilon}{\theta}\left[mc_t - \frac{\epsilon - 1}{\epsilon}\right] + \dot{\pi}_t.$$

B.4 Marginal propensities to invest

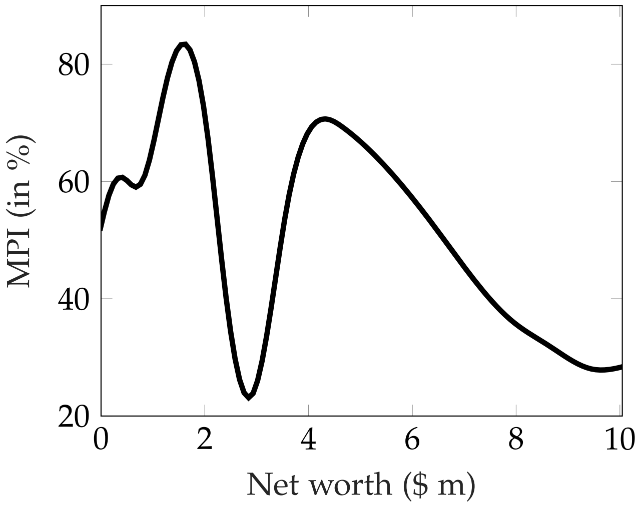


Figure 3.B6: Marginal propensity to invest (MPI) in the private business out of a transfer of $500 into the liquid account over one quarter.

Appendix C Further Empirical Evidence on Business Returns

First, we estimate the relationship between net worth and business returns nonparametrically using kernel-weighted local polynomial smoothing with an Epanechnikov kernel. Figure 3.C7 shows the results, which paint a very similar picture as Figure 3.7 in the main text. Households with net worth of $100,000 make an average return of almost 100% while households with net worth around $50,000,000 are estimated to earn an average return of about 35%. Note that we are considering average returns here which are larger than the median returns in Figure 3.7 as the distribution of returns is right-skewed.

Next, we estimate the relationship between net worth and business returns from the linear regression

$$r^e_{it} = \alpha + \beta \ln(\text{net worth}_{it}) + \gamma X_{it} + u_{it}. \tag{3.17}$$

Here, X is a vector of controls and u is an error term. The coefficient of interest is β which tells us by how many percentage points business returns change when net worth increases by one percent.

Table 3.C6 presents the estimates obtained when pooling all SCF waves. The first column shows the estimate for β we get without any additional controls. It is significantly smaller than zero and tells us that a 1% increase in net worth is associated with a decline in the return on business investment of 0.148 percentage points. In column three we control for household demographics such as age, education, marital status and the number of children. We also include fixed effects for the legal form of the business, the household's self-reported risk attitude and the survey year. With these controls, we get an estimate for β of -0.165.

As entrepreneurs can potentially hold multiple private businesses at the same time—something that we have abstracted from in our model—we additionally control for the number of businesses the entrepreneur operates in columns three and four. We find a negative effect on the return of total business capital, which appears intuitive. By running multiple businesses entrepreneurs diversify their portfolio so that the idiosyncratic risk associated with their total business investment becomes smaller. Hence, they are willing to accept a lower risk premium so that average returns on total private business investment are lower for them.

A potential concern with these results is the following. Because firm value affects our measure of business returns negatively as it enters the denominator, other things equal, households who overstate the value of their business exhibit smaller business returns as well as higher net worth. As a result, measurement error in business value could mechanically lead to a negative relationship between returns and net worth.

To account for this, we replace net worth with non-business wealth in the regression equation (3.17). The estimates are shown in columns two (without controls) and four

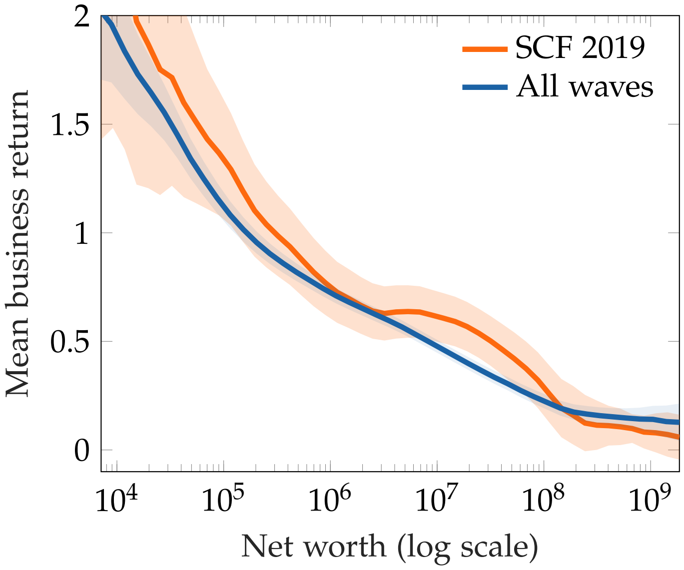


Figure 3.C7: Nonparametrically estimated relationship between business returns and net worth.
Notes: We use kernel-weighted local polynomial smoothing with an Epanechnikov kernel, confidence intervals are at the 95% level.

Table 3.C6: Regressions of business returns on net worth and non-business wealth using SCF since 1989.

	(1)	(2)	(3)	(4)
Log net worth	-0.148***		-0.165***	
	(0.00455)		(0.00635)	
Log non-business wealth		-0.0795***		-0.0500***
		(0.00504)		(0.00643)
Number businesses owned			-0.0236***	-0.0463***
			(0.00327)	(0.00389)
Demographics	No	No	Yes	Yes
Legal form FE	No	No	Yes	Yes
Risk attitude	No	No	Yes	Yes
Year FE	No	No	Yes	Yes
Observations	7288	7132	7288	7132

Notes: Demographics include age, dummies for education level, number of kids, marital status, whether the entrepreneur founded the business, and the years that have passed since the start/acquisition of the business. Risk attitude is captured by a categorical variable with four categories constructed from the respondent's answer to the question: "On a scale from zero to ten, where zero is not at all willing to take risks and ten is very willing to take risks, what number would you be on the scale?"

Table 3.C7: Summary statistics SCF since 1989.

	mean	p25	p50	p75	sd	min	max
Business return	0.60	0.05	0.19	0.60	1.04	-0.89	6.73
Net worth	30.0	0.9	4.3	20.2	90.4	0.0	1861.6
Business wealth	17.0	0.3	1.3	8.4	62.9	0.0	1300.6
Observations	7288						

Notes: Net worth and business wealth are measured in millions of US dollars, all deflated to 2019. Sample selection is as explained in main text. The displayed summary statistics do not make use of the sampling weights. Therefore, as the SCF oversamples rich individuals, the means and percentiles of net worth and business wealth appear large in comparison to equivalent statistics generated from the model (see for a comparison Figure 3.6). In all other analyses we conduct in this paper, we use the sampling weights provided by the SCF.

(with controls). We again find a statistically significant negative relationship, as would also be implied by our quantitative model. Households whose non-business wealth is one percent larger, earn a return on their business that is on average 0.05 percentage points lower.

The effect is somewhat smaller than the one we obtain for net worth. One reason is the possible effect of measurement error in business value mentioned above, which could bias the estimates in columns one and three. However, in an environment with decreasing returns, there is also an economic reason. If a household's net worth increases by 1%, she invests into her firm but at the same time increases the portfolio share of non-business assets because of the diminished return. Therefore, a 1% increase in net worth is associated with an increase in non-business wealth of more than 1%.

Portfolio shares Another testable implication of our model is that for owners of small firms, firm capital makes up a larger share of their portfolio. In other words, exposure to business wealth declines in net worth. We do not find robust evidence supporting this in the SCF data. When regressing portfolio shares (i.e., the empirical analogue of $k_e/(k_e + a + b)$) on the log of net worth ($k_e + a + b$), typical OLS estimates we find are close to zero, not smaller than zero as our model implies. There are two main explanations for this.

First, as mentioned above, there could be measurement error in k_e, which would tend to bias simple OLS estimates, as k_e appears on both sides of the equation. When we regress the ratio $k_e/(a + b)$ on the log of non-business wealth $(a + b)$, to alleviate this problem, we do find significant negative coefficients. This would imply that when non-business wealth increases, the portion of firm wealth in the household's portfolio decreases, i.e., falling exposures to firm capital, as suggested by our model. However, the issue of simultaneity clearly also affects this regression.

Second, owners of small firms might want to hold other assets for reasons we do not model. For instance, households might want to hold some liquid assets for transactional purposes. Also, if we endogenized the occupational choice, households would save up assets before actually starting their firm, as in Cagetti and De Nardi (2006). In this case, at the start of their entrepreneurial career they would not hold a portfolio that is almost completely made up of their firm, as is the case in our model.

Appendix D Monetary Policy Shocks and Portfolio Shares

D.1 Portfolio shares

This section details how we arrive at our estimates for the (log of the) portfolio shares at different percentiles p of the business return distribution. We closely follow Luetticke (2021).

We first sort entrepreneurial households in a given year t by their business return r^e. Next, we calculate the percentile of each household in the return distribution as

$$prctl_i = \frac{\sum_{j:r^e_j<r^e_i} w_j}{\sum_j w_j}$$

where w_j denote the sample weights provided by the SCF. For each percentile, we then regress the log of the portfolio share on the appropriately adjusted percentile measures. Specifically, to estimate the portfolio share at the p-th percentile, we perform a weighted regression

$$\ln(\text{portf. share}_i)\ \omega_i = \alpha\ \omega_i + \beta(prctl_i - p)\ \omega_i + u_i$$

where u is an error term and the weight we use for observation i is

$$\omega_i = \sqrt{w_i \phi\left(\frac{prctl_i - p}{0.1}\right)},$$

where $\phi(\cdot)$ corresponds to the probability density function of a standard normal distribution. The estimate of the intercept α is our estimate of the log of the portfolio share at percentile p for the year t.

D.2 From monthly to annual shock series

To convert the monthly monetary policy shock series provided by Ramey (2016) into an annual series, we follow the approach proposed by Ottonello and Winberry (2020) and Meier and Reinelt (2020). In particular, we attribute a monthly shock fully to our yearly shock only if it takes place in January. If it takes place later in the year, we partly attribute the shock to the current year and partly to the next year. We use the monthly series of shocks ϵ^m_t from Ramey (2016) to construct annual shocks ϵ^y_t according to

$$\epsilon^y_t = \sum_{\tau\in\mathcal{M}(t)} \phi(\tau,t)\cdot\epsilon^m_\tau + \sum_{\tau\in\mathcal{M}(t-1)} (1-\phi(\tau,t-1))\cdot\epsilon^m_\tau,$$

where $\mathcal{M}(t)$ is the set of months in year t and

$$\phi(\tau,t) = \frac{\text{remaining number of months in year } t \text{ after announcement in month } \tau}{12}.$$

Putting more weight on shocks early in the current year and late in the previous year allows us to more reliably inspect the response of portfolio shares "on impact", i.e., for horizon $h = 0$. However, as some respondents answered the survey in the early months of a given year and therefore potentially before some of the monthly shocks of that year materialized, the estimates of $\beta_{p,0}$ have to be interpreted with some caution even when using this particular weighting of monthly shocks.[28]

D.3 Discussion and robustness

Given that the SCF is a repeated cross-section and not a panel, the identifying assumption that we make is that the characteristics of entrepreneurial households within a given percentile of the business return distribution stay unchanged over time. This assumption appears reasonable for entrepreneurs with firms in the middle of the firm size distribution and hence with close to median returns. Their business values and net worth by construction assume relatively common values, and therefore the households themselves are not likely to be unusual in terms of observed and unobserved characteristics. Also, the non-parametric estimation of portfolio shares ensures that for the percentiles in the middle of the return distribution we include information on portfolio shares from many neighboring percentiles. This makes the estimates for the middle percentiles less sensitive to individual observations in percentile p at year t. Therefore, we are confident that the portfolio reaction at the median of the return distribution is well identified.

Both for very small and very large firm owners, the identifying assumption might be less credible. On the one hand, there could be considerable turnover due to entry and exit of firms among the small firm owners, confounding our results at the upper end of the return distribution. Very wealthy entrepreneurs, on the other hand, with businesses producing returns at the low end of the return distribution, might possess some peculiar characteristics that are not shared by entrepreneurs at the same extreme position in the return distribution in a different year. For both of these groups, at the high and low end of the return distribution, by definition there are few neighboring percentiles, and hence individual observations can influence the estimate of the portfolio share relatively strongly.

To address this issue, we first run regressions of the observed portfolio shares on various observable characteristics of the households. The controls are the same as in columns three and four of Table 3.C6 in Appendix C. We then subtract the predicted portfolio shares from the actual shares, and then estimate the portfolio shares $\gamma_{p,t}$ for each year and percentile of the return distribution as described above, but this time using the residual portfolio shares. Last, we run (3.9) using the new estimates of the portfolio shares $\gamma_{p,t}$. The results are displayed in the right panel of Figure 3.8 in the

---

[28] We also performed our analysis using simply the sum of all shocks occurring in a given year. The results are very similar.

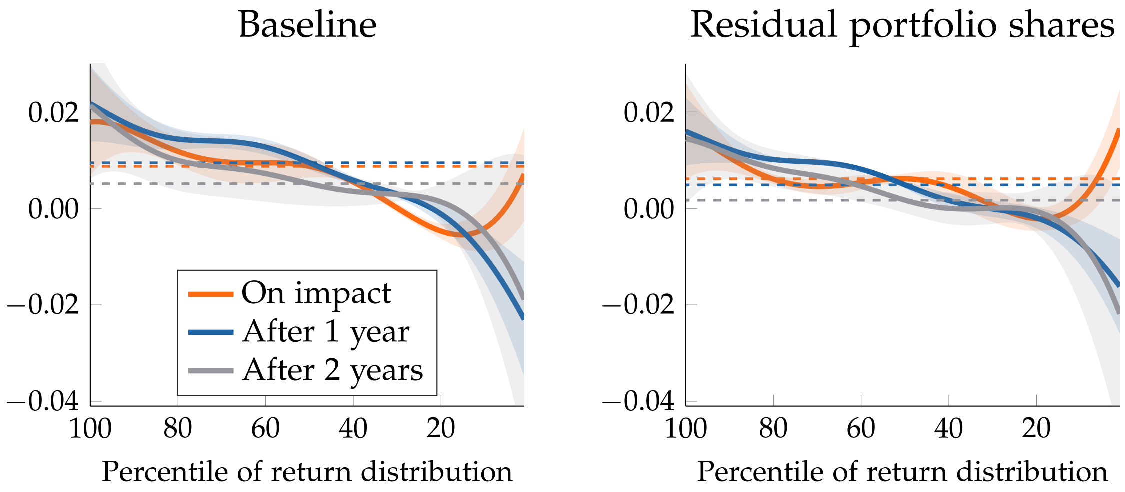


Figure 3.D8: Impulse responses of portfolio shares to Gertler and Karadi (2015) monetary policy shock.

Notes: Change in the logarithm of portfolio shares following a 25 basis points expansionary monetary policy shock by business return percentile. The dashed lines depict the responses at the median of the return distribution. Confidence bands are at the 66% level.

main text. They are very similar to the ones in our baseline specification, though the portfolio responses at the median are more muted. The general shape, however, and therefore the results regarding heterogeneity of responses highlighted above, are not affected by using residual portfolio shares instead of the actual ones.

D.4 Gertler and Karadi (2015) shocks

In our baseline specification we used the Romer & Romer shock series as instruments for the federal funds rate. Here, we instead employ the shock series derived by Gertler and Karadi (2015) who use high-frequency data to identify monetary policy surprises. We follow Ramey (2016) in focusing on the series that uses the 3-month ahead fed funds futures as instruments. Figure 3.D8 shows the results.

The median responses are very similar to those found when using the Romer & Romer shocks series. We find the robustness of the results in this regard encouraging, given that the time window covered by the Gertler and Karadi (2015) shocks (and the SCF waves that we use to estimate portfolio shares) has only a small overlap with that of the Romer & Romer shocks. Regarding the heterogeneity of responses, the u-shape that we find when using the Romer & Romer shocks only appears in the impact response to the shock, and most clearly when using the residual portfolio shares.

Bibliography

Acemoglu, Daron, Andrea Manera, and Pascual Restrepo. 2020. *Does the US Tax Code Favor Automation?* National Bureau of Economic Research Working Paper 27052.

Adam, Klaus, and Junyi Zhu. 2016. "Price-Level Changes And The Redistribution Of Nominal Wealth Across The Euro Area". *Journal of the European Economic Association* 14 (4): 871–906.

Ahn, Sehyoun, Greg Kaplan, Benjamin Moll, Thomas Winberry, and Christian Wolf. 2018. "When Inequality Matters for Macro and Macro Matters for Inequality". Chapter 1 in *NBER Macroeconomics Annual 2017, Volume 32,* 1–75. University of Chicago Press.

Almgren, Mattias, Jose E Gallegos, John Kramer, and Ricardo Lima. Forthcoming. "Monetary Policy and Liquidity Constraints: Evidence from the Euro Area". *American Economic Journal: Macroeconomics.*

Alpanda, Sami, and Sarah Zubairy. 2019. "Household Debt Overhang and Transmission of Monetary Policy". *Journal of Money, Credit and Banking* 51 (5): 1265–1307.

Altavilla, Carlo, Luca Brugnolini, Refet S. Gürkaynak, Roberto Motto, and Giuseppe Ragusa. 2019. "Measuring Euro Area Monetary Policy". *Journal of Monetary Economics* 108:162–179.

Alvaredo, Facundo, Anthony B Atkinson, and Salvatore Morelli. 2016. *Top wealth shares in the UK over more than a century.* WID.world Working Paper Series 2017/2.

Alvaredo, Facundo, Lucas Chancel, Thomas Piketty, Emmanuel Saez, and Gabriel Zucman. 2018. *The World Inequality Report.* Harvard University Press.

Alves, Felipe, Greg Kaplan, Benjamin Moll, and Giovanni L. Violante. 2020. "A Further Look at the Propagation of Monetary Policy Shocks in HANK". *Journal of Money, Credit and Banking* 52 (S2): 521–559.

Andersen, Asger Lau, Niels Johannesen, Mia Jørgensen, and José-Luis Peydró. 2021. "Monetary Policy and Inequality". Unpublished.

Ascari, Guido, and Timo Haber. 2022. "Non-linearities, State-Dependent Prices and the Transmission Mechanism of Monetary Policy". *The Economic Journal* 132 (641): 37–57.

Aschauer, David Alan. 1989. “Does Public Capital Crowd Out Private Capital?” *Journal of Monetary Economics* 24 (2).

Asker, John, Allan Collard-Wexler, and Jan De Loecker. 2014. “Dynamic Inputs and Resource (Mis)Allocation”. *Journal of Political Economy* 122 (5): 1013–1063.

Asker, John, Joan Farre-Mensa, and Alexander Ljungqvist. 2015. “Corporate Investment and Stock Market Listing: A Puzzle?” *The Review of Financial Studies* 28 (2): 342–390.

Auclert, Adrien. 2019. “Monetary Policy and the Redistribution Channel”. *American Economic Review* 109 (6): 2333–2367.

Auclert, Adrien, Matthew Rognlie, and Ludwig Straub. 2018. *The Intertemporal Keynesian Cross.* National Bureau of Economic Research Working Paper 25020.

———. 2020. “Micro Jumps, Macro Humps: Monetary Policy and Business Cycles in an Estimated HANK Model”. Unpublished.

Auerbach, Alan J, and Yuriy Gorodnichenko. 2013. “Fiscal Multipliers in Recession and Expansion”. In *Fiscal Policy after the Financial Crisis,* edited by Alberto Alesina and Francesco Giavazzi, 63–98. Chicago, IL: University of Chicago Press.

Bahaj, Saleem, Angus Foulis, Gabor Pinter, and Paolo Surico. Forthcoming. “Employment and the Collateral Channel of Monetary Policy”. *Journal of Monetary Economics.*

Barnes, Aaron. 2021. *Personal Wealth, 2016.* Statistics of Income Bulletin Spring 2021. Internal Revenue Service.

Baxter, Marianne, and Robert G King. 1993. “Fiscal Policy in General Equilibrium”. *American Economic Review* 83 (3): 315–334.

Beaudry, Paul, and Franck Portier. 2006. “Stock Prices, News, and Economic Fluctuations”. *American Economic Review* 96 (4): 1293–1307.

———. 2007. “When Can Changes in Expectations Cause Business Cycle Fluctuations in Neo-Classical Settings?” *Journal of Economic Theory* 135 (1): 458–477.

Benhabib, Jess, Alberto Bisin, and Shenghao Zhu. 2015. “The Wealth Distribution in Bewley Economies with Capital Income Risk”. *Journal of Economic Theory* 159:489–515.

Beraja, Martin, Erik Hurst, and Juan Ospina. 2019. “The Aggregate Implications of Regional Business Cycles”. *Econometrica* 87 (6): 1789–1833.

Bilbiie, Florin O. 2008. “Limited Asset Markets Participation, Monetary Policy and (Inverted) Aggregate Demand Logic”. *Journal of Economic Theory* 140 (1): 162–196.

———. 2020. “The New Keynesian cross”. *Journal of Monetary Economics* 114:90–108.

BIS. 2021. “The distributional footprint of monetary policy”. In *BIS Annual Economic Report 2021,* 39–64. Bank of International Settlements.

Blanchard, Olivier, and Jordi Galí. 2010. “Labor Markets and Monetary Policy: A New Keynesian Model with Unemployment”. *American Economic Journal: Macroeconomics* 2 (2): 1–30.

Boar, Corina, Denis Gorea, and Virgiliu Midrigan. 2022. *Why Are Returns to Private Business Wealth So Dispersed?* National Bureau of Economic Research Working Paper 29705.

Boehm, Christoph E. 2020. “Government Consumption and Investment: Does the Composition of Purchases Affect the Multiplier?” *Journal of Monetary Economics* 115:80–93.

Bom, Pedro R.D., and Jenny E. Ligthart. 2014. “What Have We Learned from Three Decades of Research on the Productivity of Public Capital?” *Journal of Economic Surveys* 28 (5): 889–916.

Bouakez, Hafedh, Michel Guillard, and Jordan Roulleau-Pasdeloup. 2017. “Public Investment, Time to Build, and the Zero Lower Bound”. *Review of Economic Dynamics* 23:60–79.

Brinca, Pedro, Hans A. Holter, Per Krusell, and Laurence Malafry. 2016. “Fiscal multipliers in the 21st century”. *Journal of Monetary Economics* 77:53–69.

Broer, Tobias, Niels-Jakob Harbo Hansen, Per Krusell, and Erik Öberg. 2019. “The New Keynesian Transmission Mechanism: A Heterogeneous-Agents Perspective”. *Review of Economic Studies:* 1–25.

Cagetti, Marco, and Mariacristina De Nardi. 2006. “Entrepreneurship, Frictions, and Wealth”. *Journal of Political Economy* 114 (5): 835–870.

Carlino, Gerald, and Robert DeFina. 1998. “The Differential Regional Effects of Monetary Policy”. *Review of Economics and Statistics* 80 (4): 572–587.

———. 1999. “The differential regional effects of monetary policy: Evidence from the US states”. *Journal of Regional science* 39 (2): 339–358.

Challe, Edouard. 2020. “Uninsured Unemployment Risk and Optimal Monetary Policy in a Zero-Liquidity Economy”. *American Economic Journal: Macroeconomics* 12 (2): 241–283.

Chetty, Raj. 2008. “Moral Hazard versus Liquidity and Optimal Unemployment Insurance”. *Journal of Political Economy* 116 (2): 173–234.

Chodorow-Reich, Gabriel, Laura Feiveson, Zachary Liscow, and William Gui Woolston. 2012. “Does State Fiscal Relief During Recessions Increase Employment? Evidence from the American Recovery and Reinvestment Act”. *American Economic Journal: Economic Policy* 4 (3): 118–145.

Chodorow-Reich, Gabriel, and Loukas Karabarbounis. 2016. “The Cyclicality of the Opportunity Cost of Employment”. *Journal of Political Economy* 124 (6): 1563–1618.

Chow, Gregory C, and An-loh Lin. 1971. “Best Linear Unbiased Interpolation, Distribution, and Extrapolation of Time Series by Related Series”. *The Review of Economics and Statistics* 53 (4): 372–375.

Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans. 1999. “Monetary policy shocks: What have we learned and to what end?” Chapter 2 in *Handbook of Macroeconomics,* edited by John B Taylor and Michael Woodford, 1:65–148. PART A. Amsterdam: Elsevier.

———. 2005. “Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy”. *Journal of Political Economy* 113 (1): 1–45.

Cloyne, James, Clodomiro Ferreira, Maren Froemel, and Paolo Surico. Forthcoming. “Monetary Policy, Corporate Finance and Investment”. *Journal of the European Economic Association.*

Cloyne, James, and Patrick Hürtgen. 2016. “The macroeconomic effects of monetary policy: A new measure for the United Kingdom”. *American Economic Journal: Macroeconomics* 8 (4): 75–102.

Coibion, Olivier. 2012. “Are the effects of monetary policy shocks big or small?” *American Economic Journal: Macroeconomics* 4 (2): 1–32.

Coibion, Olivier, Yuriy Gorodnichenko, Lorenz Kueng, and John Silvia. 2017. “Innocent bystanders? Monetary policy and inequality”. *Journal of Monetary Economics* 88:70–89.

Cooley, Thomas F., and Vincenzo Quadrini. 2001. “Financial Markets and Firm Dynamics”. *American Economic Review* 91 (5): 1286–1310.

Cubas, German. 2020. “Public Capital and Economic Development”. *The Economic Journal* 130 (632): 2354–2381.

De Nardi, Mariacristina, Phil Doctor, and Spencer D Krane. 2007. “Evidence on entrepreneurs in the United States: Data from the 1989 – 2004 Survey of Consumer Finances”. *Economic Perspectives* 31 (4): 18–36.

DeBacker, Jason, Vasia Panousi, and Shanthi Ramnath. Forthcoming. "A Risky Venture: Income Dynamics within the Non-Corporate Private Business Sector". *American Economic Journal: Macroeconomics.*

Den Haan, Wouter J., and Georg Kaltenbrunner. 2009. "Anticipated Growth and Business Cycles in Matching Models". *Journal of Monetary Economics* 56 (3): 309–327.

Den Haan, Wouter J., Garey Ramey, and Joel Watson. 2000. "Job Destruction and Propagation of Shocks". *American Economic Review* 90 (3): 482–498.

Den Haan, Wouter J., Pontus Rendahl, and Markus Riegler. 2017. "Unemployment (Fears) and Deflationary Spirals". *Journal of the European Economic Association* 16 (5): 1281–1349.

Dossche, Maarten, Jiri Slacalek, and Guido Wolswijk. 2021. "Monetary Policy and Inequality". *Economic Bulletin Articles* 2.

Gertler, Mark, Christopher Huckfeldt, and Antonella Trigari. 2020. "Unemployment Fluctuations, Match Quality, and the Wage Cyclicality of New Hires". *The Review of Economic Studies* 87 (4): 1876–1914.

Gertler, Mark, and Peter Karadi. 2015. "Monetary Policy Surprises, Credit Costs, and Economic Activity". *American Economic Journal: Macroeconomics* 7 (1): 44–76.

Gornemann, Nils, Keith Kuester, and Makoto Nakajima. 2016. "Doves for the Rich, Hawks for the Poor? Distributional Consequences of Monetary Policy". *International Finance Discussion Paper* 2016 (1167): 1–40.

Gutiérrez, Germán, and Thomas Philippon. 2017. "Investmentless Growth: An Empirical Investigation". *Brookings Papers on Economic Activity* 48 (2): 89–190.

Guvenen, Fatih, Fatih Karahan, Serdar Ozkan, and Jae Song. 2021. "What Do Data on Millions of U.S. Workers Reveal About Lifecycle Earnings Dynamics?" *Econometrica* 89 (5): 2303–2339.

Hagedorn, Marcus, and Iourii Manovskii. 2008. "The Cyclical Behavior of Equilibrium Unemployment and Vacancies Revisited". *American Economic Review* 98 (4): 1692–1706.

Hall, Robert E. 2003. *Wage Determination and Unemployment Fluctuations.* National Bureau of Economic Research Working Paper 9967.

———. 2005. "Employment Fluctuations with Equilibrium Wage Stickiness". *American Economic Review* 95 (1): 50–65.

Hosios, Arthur J. 1990. "On the Efficiency of Matching and Related Models of Search and Unemployment". *The Review of Economic Studies* 57 (2): 279–298.

Hubmer, Joachim, Per Krusell, and Anthony A. Smith Jr. 2021. "Sources of US Wealth Inequality: Past, Present, and Future". *NBER Macroeconomics Annual* 35 (1): 391–455.

Hyatt, Henry R., and James R. Spletzer. 2016. "The shifting job tenure distribution". SOLE/EALE conference issue 2015, *Labour Economics* 41:363–377.

Jacobson, Darien B., Brian G. Raub, and Barry W. Johnson. 2007. "The Estate Tax: Ninety Years and Counting". *Statistics of Income Bulletin* 1 (27): 118–128.

Jeenas, Priit. 2019. "Firm Balance Sheet Liquidity, Monetary Policy Shocks, and Investment Dynamics". Unpublished.

Jordà, Òscar. 2005. "Estimation and Inference of Impulse Responses by Local Projections". *American Economic Review* 95 (1): 161–182.

Kaplan, Greg, Benjamin Moll, and Giovanni L. Violante. 2018. "Monetary Policy According to HANK". *American Economic Review* 108 (3): 697–743.

Kaplan, Greg, Giovanni L. Violante, and Justin Weidner. 2014. "The Wealthy Hand-to-Mouth". *Brookings Papers on Economic Activity* Spring:77–153.

Kopczuk, Wojciech. 2015. "What Do We Know about the Evolution of Top Wealth Shares in the United States?" *Journal of Economic Perspectives* 29 (1): 47–66.

Kopczuk, Wojciech, and Emmanuel Saez. 2004. "Top Wealth Shares in the United States, 1916-2000: Evidence from Estate Tax Returns". *National Tax Journal* 57 (2, Part 2): 445–487.

Krebs, Tom, and Martin Scheffel. 2017. "Labor Market Institutions and the Cost of Recessions". Unpublished.

Krusell, Per, Toshihiko Mukoyama, and Ayşegül Şahin. 2010. "Labour-Market Matching with Precautionary Savings and Aggregate Fluctuations". *The Review of Economic Studies* 77 (4): 1477–1507.

Krusell, Per, and Anthony A. Smith Jr. 1998. "Income and Wealth Heterogeneity in the Macroeconomy". *Journal of Political Economy* 106 (5): 867–896.

Kuhn, Moritz, Moritz Schularick, and Ulrike I. Steins. 2020. "Income and Wealth Inequality in America, 1949–2016". *Journal of Political Economy* 128 (9): 3469–3519.

Landais, Camille, Pascal Michaillat, and Emmanuel Saez. 2018. "A Macroeconomic Approach to Optimal Unemployment Insurance: Applications". *American Economic Journal: Economic Policy* 10 (2): 182–216.

Leahy, John V., and Aditi Thapar. 2019. *Demographic Effects on the Impact of Monetary Policy.* National Bureau of Economic Research Working Paper 26324.

Leduc, Sylvain, and Daniel Wilson. 2013. "Roads to Prosperity or Bridges to Nowhere? Theory and Evidence on the Impact of Public Infrastructure Investment". *NBER Macroeconomics Annual* 27 (1): 89–142.

Leeper, Eric M., Todd B. Walker, and Shu-Chun S. Yang. 2010. "Government Investment and Fiscal Stimulus". *Journal of Monetary Economics* 57 (8): 1000–1012.

Levine, Ross, and Yona Rubinstein. 2020. *Selection into Entrepreneurship and Self-Employment.* Centre for Economic Policy Research Discussion Paper 15143.

Lucas, Robert. 1978. "On the Size Distribution of Business Firms". *Bell Journal of Economics* 9 (2): 508–523.

Luetticke, Ralph. 2021. "Transmission of Monetary Policy with Heterogeneity in Household Portfolios". *American Economic Journal: Macroeconomics* 13 (2): 1–25.

McKay, Alisdair, and Ricardo Reis. 2021. "Optimal Automatic Stabilizers". *The Review of Economic Studies.*

Meier, Matthias, and Timo Reinelt. 2020. *Monetary Policy, Markup Dispersion, and Aggregate TFP.* CRC TR 224 Discussion Paper 161. University of Bonn and University of Mannheim.

Melcangi, Davide, and Vincent Sterk. 2020. *Stock Market Participation, Inequality, and Monetary Policy.* Federal Reserve Bank of New York Staff Report 932.

Merz, Monika. 2010. "Comment to "Unemployment Fiscal Multiplier" by Tommaso Monacelli, Roberto Perotti, and Antonella Trigari". *Journal of Monetary Economics* 57 (5): 554–556.

Michaillat, Pascal. 2014. "A Theory of Countercyclical Government Multiplier". *American Economic Journal: Macroeconomics* 6 (1): 190–217.

Michaillat, Pascal, and Emmanuel Saez. 2018. "Optimal Public Expenditure with Inefficient Unemployment". *The Review of Economic Studies* 86 (3): 1301–1331.

Mitman, Kurt, and Stanislav Rabinovich. 2015. "Optimal Unemployment Insurance in an Equilibrium Business-Cycle Model". *Journal of Monetary Economics* 71:99–118.

Monacelli, Tommaso, Roberto Perotti, and Antonella Trigari. 2010. "Unemployment fiscal multipliers". *Journal of Monetary Economics* 57 (5): 531–553.

Mortensen, Dale T., and Christopher A. Pissarides. 1994. "Job Creation and Job Destruction in the Theory of Unemployment". *The Review of Economic Studies* 61 (3): 397–415.

Munnell, Alicia. 1990. "Why Has Productivity Growth Declined? Productivity and Public Investment". *New England Economic Review:* 3–22.

Newey, Whitney K, and Kenneth D West. 1987. "A Simple, Positive Semi-definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix". *Econometrica* 55 (3): 703–708.

OECD. 2020. "OECD Indicators of Employment Protection". OECD. `www.oecd.org/employment/protection`.

Ottonello, Pablo, and Thomas Winberry. 2020. "Financial Heterogeneity and the Investment Channel of Monetary Policy". *Econometrica* 88 (6): 2473–2502.

Owyang, Michael T., and Howard J. Wall. 2009. "Regional VARs and the channels of monetary policy". *Applied Economics Letters* 16 (12): 1191–1194.

Patterson, Christina. 2022. "The Matching Multiplier and the Amplification of Recessions". Unpublished.

Pereira, Alfredo M., and Rafael Flores de Frutos. 1999. "Public Capital Accumulation and Private Sector Performance". *Journal of Urban Economics* 46 (2): 300–322.

Petrongolo, Barbara, and Christopher A Pissarides. 2001. "Looking into the Black Box: A Survey of the Matching Function". *Journal of Economic Literature* 39 (2): 390–431.

Piketty, Thomas. 2014. *Capital in the Twenty-First Century:* Cambridge, MA: Harvard University Press.

Piketty, Thomas, Emmanuel Saez, and Gabriel Zucman. 2018. "Distributional National Accounts: Methods and Estimates for the United States". *The Quarterly Journal of Economics* 133 (2): 553–609.

Pissarides, Christopher A. 1985. "Short-Run Equilibrium Dynamics of Unemployment, Vacancies, and Real Wages". *The American Economic Review* 75 (4): 676–690.

———. 2009. "The Unemployment Volatility Puzzle: Is Wage Stickiness the Answer?" *Econometrica* 77 (5): 1339–1369.

Poschke, Markus. 2013. "Who becomes an entrepreneur? Labor market prospects and occupational choice". *Journal of Economic Dynamics and Control* 37 (3): 693–710.

Ramey, Valerie A. 2011. "Can Government Purchases Stimulate the Economy?" *Journal of Economic Literature* 49 (3): 673–685.

———. 2016. "Macroeconomic shocks and their propagation". Chapter 3 in *Handbook of Macroeconomics,* 1st edition, edited by Harald Uhlig and John B. Taylor, 2:71–162. Amsterdam: Elsevier B.V.

———. 2020. *The Macroeconomic Consequences of Infrastructure Investment.* National Bureau of Economic Research Working Paper 27625.

Ramey, Valerie A., and Sarah Zubairy. 2018. "Government Spending Multipliers in Good Times and in Bad: Evidence from US Historical Data". *Journal of Political Economy* 126 (2): 850–901.

Ravn, Morten O, and Vincent Sterk. 2020. "Macroeconomic Fluctuations with HANK & SAM: an Analytical Approach". *Journal of the European Economic Association* 19 (2): 1162–1202.

Rendahl, Pontus. 2016. "Fiscal Policy in an Unemployment Crisis". *The Review of Economic Studies* 83 (3): 1189–1224.

Romer, Christina D., and David H. Romer. 2004. "A New Measure of Monetary Shocks: Derivation and Implications". *American Economic Review* 94 (4): 1055–1084.

Rotemberg, Julio J. 1982. "Monopolistic Price Adjustment and Aggregate Output". *The Review of Economic Studies* 49 (4): 517.

Saez, Emmanuel, and Gabriel Zucman. 2016. "Wealth inequality in the United States since 1913: Evidence From Capitalized Income Tax Data". *Quarterly Journal of Economics* 131 (2): 519–578.

Schmitt-Grohé, Stephanie, and Martín Uribe. 2012. "What's News in Business Cycles". *Econometrica* 80 (6): 2733–2764.

Schwartz, Marvin. 1988. "Estimates of Personal Wealth, 1982—A Second Look". *Statistics of Income Bulletin* 7 (4): 31–43.

Serrato, Juan Carlos Suárez, and Philippe Wingender. 2016. *Estimating Local Fiscal Multipliers.* National Bureau of Economic Research Working Paper 22425.

Shimer, Robert. 2005. "The Cyclical Behavior of Equilibrium Unemployment and Vacancies". *American Economic Review* 95 (1): 25–49.

———. 2010. *Labor Markets and Business Cycles.* Princeton, NJ: Princeton University Press.

———. 2012. "Reassessing the Ins and Outs of Unemployment". *Review of Economic Dynamics* 15 (2): 127–148.

Slacalek, Jiri, Oreste Tristani, and Giovanni L. Violante. 2020. "Household Balance Sheet Channels of Monetary Policy: A Back of the Envelope Calculation for the Euro Area". *Journal of Economic Dynamics and Control* 115 (C).

Smith, Matthew, Owen M. Zidar, and Eric Zwick. 2021. *Top Wealth in America: New Estimates and Implications for Taxing the Rich.* National Bureau of Economic Research Working Paper 29374.

Stock, James H., and Mark W. Watson. 2018. "Identification and Estimation of Dynamic Causal Effects in Macroeconomics Using External Instruments". *Economic Journal* 128 (610): 917–948.

Summers, Lawrence. 2009. *A Weakened Economy: How to Respond?, 110th Congress (Testimony of Lawrence Summers).*

Tan, Eugene. 2021. "Entrepreneurial Investment Dynamics and the Wealth Distribution". Unpublished.

Tenreyro, Silvana, and Gregory Thwaites. 2016. "Pushing on a String: US Monetary Policy Is Less Powerful in Recessions". *American Economic Journal: Macroeconomics* 8 (4): 43–74.

Werning, Iván. 2015. *Incomplete Markets and Aggregate Demand.* National Bureau of Economic Research Working Paper 21448.

Wilson, Daniel J. 2012. "Fiscal Spending Jobs Multipliers: Evidence from the 2009 American Recovery and Reinvestment Act". *American Economic Journal: Economic Policy* 4 (3): 251–282.

Wong, Arlene. 2021. "Refinancing and The Transmission of Monetary Policy to Consumption". Unpublished.

Xavier, Inês. 2021. "Wealth Inequality in the US: the Role of Heterogeneous Returns". Unpublished.