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Labor Market Polarization with Hand-to-Mouth Households

Johannes Wacks *

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Abstract

Over the recent decades, wide-spread automation has led to a shift of the US labor force from occupations intensive in routine tasks into occupations intensive in manual and abstract tasks. I integrate routine-biased technological change into an incomplete markets model with occupation-specific human capital. I use the model to study the transition between steady states pre and post labor market polarization in general equilibrium. When human capital is occupation-specific and wages in the routine occupations relative to the other occupations fall over time, occupational choices become dynamic investment decisions. When households are close to the borrowing constraint, their occupational choices are distorted and they optimally choose to work in the routine occupations for longer than households who have accumulated a buffer stock of savings. I show that in a counterfactual economy, in which all workers choose occupations as if they were hand-to-mouth, the fall in routine labor is protracted by about three years compared to what was actually observed. I use the model to discuss several labor market policies. Incentivizing experienced routine workers to switch to the manual or abstract occupations, by paying them a government transfer, increases social welfare and average output. Empirically, I show that the friction I study is highly relevant, as about 34% of the households working in routine occupations live hand-to-mouth.

JEL Codes: E21, E24, J24, J62, D31

Keywords: Labor markets, Polarization, Wealth distribution, Hand-to-mouth

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1 Introduction

The US labor market has become increasingly polarized since the 1980s. As investments in Information and Communication Technologies (ICT) capital have become ever cheaper, a growing share of jobs has become automated and replaced by machines. Especially susceptible to destruction have been the jobs that are intensive in routine, i.e. easily codifiable tasks, such as factory workers, bookkeepers and clerical workers. Consequently, the share of hours worked in routine occupations, which are predominantly found in the middle of the income distribution, has declined substantially in recent decades.

Mirroring this decline, the share of labor employed in occupations that are intensive in manual or in abstract tasks has increased, and wages in these occupations relative to the routine occupations have risen.¹ Manual occupations, e.g. waiters, bus drivers, or nursing aides, often require non-trivial human interactions or usage of eyes, hands and feet, in ways that are difficult to master for machines. Work in abstract occupations, such as in management, teaching, or public service, is usually viewed as complementary to and benefiting from the introduction of ICT capital. In sum, the trend of polarizing labor markets has necessitated, and still requires, a major shift of the US workforce away from the routine and into the manual and abstract occupations.

The main contribution of this paper is to embed this trend of polarizing labor markets into a general equilibrium model of the US economy which features uninsurable idiosyncratic labor income risk and a large share of households who are hand-to-mouth, i.e. who own few liquid assets or are up against their borrowing constraint. Human capital in the model is occupation-specific. This makes the occupational choice of workers during the labor market transition, in which relative wages between occupations change over time, a dynamic investment decision. As households close to the borrowing constraint value income in the near future relatively highly, and discount income further ahead in the future relatively strongly, they have incentives to work in the routine occupations until a later point in time than households who have saved up a buffer of assets. I therefore augment previous quantitative models of labor market polarization to account for an important dynamic distortion that has so far not been studied in detail.²

The model endogenously generates a share of about 30% of households who are hand-to-mouth, as observed in US data, by introducing two assets that households can use for saving. One asset is liquid, the other one is subject to a portfolio adjustment cost and hence illiquid. Households have a fixed skill type, die stochastically, and endogenously sort into one of three occupations (manual, routine, abstract), accumulating human capital on the job that is specific to their current occupation. Perfectly competitive firms produce output

¹These empirical patterns have been documented, among others, by Acemoglu and Autor (2011), Autor and Dorn (2013), Autor, Levy, et al. (2003), Cortes (2016), and Cortes, Jaimovich, and Siu (2017).

²Related quantitative models of labor market polarization, e.g. Jaimovich, Saporta-Eksten, et al. (2020), Kikuchi and Kitao (2020), Moll et al. (2021), and vom Lehn (2020), are discussed at the end of this section.

using capital as well as labor from all three occupations.

I use the model to study the labor market transition between two steady states, driven by an exogenous fall in the relative price of ICT capital. During the transition, the share of hours worked in the routine occupations can decline along two margins. On the one hand, new labor market entrants can choose to no longer enter the routine occupations that are in secular decline. On the other hand, workers who have formerly been employed in the routine occupations can leave them by switching to other occupations.

Occupational choices in the model at each point in time depend on the households' wealth holdings. This has an effect on both of these adjustment margins of the labor market. Firstly, young labor market entrants, when hand-to-mouth, choose to begin their work life in the routine occupations until a later point in time compared to households who have saved up a buffer of liquid assets, as long as the decline in relative wages for routine work is still relatively far ahead in the future. Secondly, while all experienced routine workers are averse to the drop in earnings that a switch to the manual or the abstract occupations entails (as their occupation-specific human capital becomes less applicable), those that are hand-to-mouth are even more reluctant to make such a switch than those that are well-insured.

Two main results stand out when analysing the transition between 1980 and the final steady state. First, the fact that many households live hand-to-mouth slows down the transition of the workforce away from the routine occupations. Occupational attachment becomes "sticky" in an economy with occupational human capital and hand-to-mouth households, for the reasons explained above. I conduct an exercise in which I compare the baseline transition to a transition in which all households counterfactually make their occupational choices using the policy function of the average hand-to-mouth household. In terms of effective labor employed in routine occupations, the labor market transition in the counterfactual lags behind that of the baseline economy on average by about three years between 2000 and 2020.

The second main result concerns the main policy experiment that I conduct. To dampen the drop in earnings caused by switching occupations and to subsidize occupations for which labor demand is rising, I introduce a government transfer to formerly experienced routine workers who switch to the manual or abstract occupations. This policy directly addresses the key friction in the model. It provides insurance to the workers most affected by technological change following the temporary fall in labor earnings that they face until they have accumulated human capital in their new occupation. I find that replacing 50% of the average earnings drop of experienced routine workers over several years leads to the largest welfare gain compared to the baseline scenario without government intervention. This policy, paid for by raising labor income taxes and therefore not benefiting every household in the economy, allows medium-skilled workers born in 1980 (1970) to increase their expected lifetime consumption by 0.9% (0.3%).

These welfare gains for the medium-skilled workers are in part driven by general equilib-

rium effects of the policy. By smoothing the transition for experienced routine workers into new occupations, more of them optimally make such a switch, which puts upward pressure on the routine wages during the transition. This benefits all remaining routine workers for whom leaving the occupation is not optimal despite the transfer payment offered. I also show that the aggregate welfare gains are not merely caused by re-distribution. Despite being financed by raising distortionary labor income taxes, the policy leads to an increase in output during the later years of the transition period. This happens because a lower supply of routine labor, which is highly substitutable with ICT capital, leads to an endogenous rise of the aggregate capital stock in the economy. This general equilibrium effect also causes a small increase of wages in the manual occupations compared to the baseline transition. The policy therefore also benefits low-skilled workers who never even pick up the government transfer. I compare these results to two other recently discussed policies: a re-training program for formerly routine workers and the temporary introduction of a tax on ICT capital. I find that while these two policies also raise overall social welfare, neither of them is as successful in doing so as the policy of replacing 50% of average lost earnings.

Empirically, I show that the friction considered in this paper is highly relevant, as a significant fraction of US households owns very few liquid assets. I show that the likelihood of being hand-to-mouth households is especially high among those groups of households who constitute the two important margins of labor market adjustment discussed above, i.e. the routine workers and those with little occupational human capital. Using data from the Survey of Consumer Finances (SCF), I classify households into the three broad occupational groups, and document for each group the share that lives hand-to-mouth. I find that the probability that a routine worker is hand-to-mouth is higher than the average probability in the economy by three to seven percentage points. To the best of my knowledge, this fact has not been documented before. Similarly, and as has been pointed out before in the literature, I document that younger households are more likely to be hand-to-mouth than older households. Interpreting age as a proxy for occupational tenure, this indicates that less experienced households are also relatively more likely to be hand-to-mouth than the average.

The rest of the paper is structured as follows. I first discuss the related literature. In Section 2 I present empirical evidence that motivates the quantitative model. In Section 3 I use a small, highly stylized model to develop the intuition for the core mechanism. The full model is presented in Section 4. In Section 5 I study the transition between two steady states, while in Section 6 I conduct the policy experiments. Section 7 concludes.

Related Literature A large empirical literature has explored the phenomenon of labor market polarization. Acemoglu and Autor (2011) point out that a notable polarization both of wage growth and of jobs has taken place in the US since the 1980s. Plotted across hourly earnings quantile, earnings changes exhibit a u-shape, featuring higher growth at low and high quantiles. Similarly, both the share of employment in high skill, high wage occupations

and low skill, low wage occupations grew over this time frame.³ In a theoretical model they link these patterns to the “routinization” hypothesis, i.e. that routine jobs of the income middle class have been increasingly automated, as in Autor, Levy, et al. (2003). Building on these insights, Autor and Dorn (2013) point out that the relative rise in earnings and employment at the bottom of the occupational skill distribution in the US can be attributed to the rise in service occupations.

Cortes, Jaimovich, and Siu (2017) document that the disappearance of routine labor over the recent decades is due to a diminished propensity to work in these occupations of certain demographic groups who are typically found in routine jobs, and only to a lesser extent to a fallen share of these demographic groups among the total US population.⁴ Based on an analysis using data from the Current Population Survey (CPS), Cortes, Jaimovich, Nekarda, et al. (2020) further find that a drop in the inflow rates from non- and unemployment into routine occupations has been an important driver of the decline in routine labor over recent decades. While I abstract from non- and unemployment in my model, I find an important quantitative role for the falling propensity to enter routine occupations of new labor market entrants in explaining the decrease in aggregate routine labor, corroborating the results of Cortes, Jaimovich, Nekarda, et al. (2020).⁵

By following individual households over many years using data from the Panel Study of Income Dynamics (PSID), Cortes (2016) offers insights into how they were affected by labor market polarization.⁶ He proposes a simple theoretical model, in which workers differ by fixed skill type, and low types endogenously sort into the manual, medium skill types into the routine and high skill types into the abstract occupations. He finds support for this assumption of a “catch-all” skill type and the proposed ordering of the occupational groups in the data. He shows that low-skilled routine workers (i.e. those earning relative low wages) were most likely to exit to the manual, and high-skilled most likely to exit to the abstract occupations during the labor market polarization. In addition, he finds that routine workers who switch to the manual or abstract occupations earn higher wages in the long run compared to those routine workers who stay. The quantitative model I lay out below, which is an extended version of his stylized model, is in line with these predictions.

There has also been recent progress in embedding labor market polarization into quantitative macroeconomic models. My model is closest to vom Lehn (2020). Households in his model are heterogeneous in skill type and endogenously sort into the three broad occupa-

³Goos et al. (2014) corroborate these empirical findings using labor market data of 16 Western European countries.

⁴These groups are white male high school dropouts and graduates, as well as young and prime-aged females with either high school diplomas or some post-secondary education.

⁵This is also in line with the findings in Adão et al. (2020). They show that employment responses to technological innovations are to a large extent driven by new generations making different skill investment choices than older cohorts before entering the labor market.

⁶Bachmann et al. (2019), Bessen et al. (2020), Dauth et al. (2020), and Edin et al. (2020), among others, provide empirical evidence on how workers in labor markets other than the US were affected by automation.

tional groups as in Cortes (2016). While in vom Lehn (2020) the household sector can be represented by a representative agent, in my model workers face uninsurable idiosyncratic income risk (Aiyagari, 1994; Bewley, 1983; Huggett, 1993). I further introduce two assets that households use for saving, to generate a realistic share of hand-to-mouth households, and occupation-specific human capital, which gives rise to the key mechanism discussed above. I also additionally allow for an intensive labor supply choice, such that progressive labor income taxation can have a dampening effect on the aggregate labor supply. This is important when studying the effects of labor market policies, which are financed by raising labor taxes in Section 6.⁷

Moll et al. (2021) develop a model based on the task-based framework from Acemoglu and Restrepo (2018b), adding ex-ante household heterogeneity in skills and dissipation shocks to wealth accumulation. They feed a trend in automation into the model to study its implications for wealth inequality, and find that automation, by driving up the interest rate on capital, leads to higher wealth inequality. I differ from Moll et al. (2021) in building a model with uninsurable idiosyncratic income risk and occupation-specific human capital, and by focusing on how labor market policies can alleviate the negative welfare effects of labor market polarization on adversely affected households in the economy. This interest is shared by Jaimovich, Saporta-Eksten, et al. (2020). However, while they focus on policies within the steady state of their model after polarization has occurred, the friction I discuss is only relevant during the transition to a new steady state. Hence, I focus on government interventions during the transition. Unlike Jaimovich, Saporta-Eksten, et al. (2020), I abstract from unemployment and non-employment in my model, both for tractability and because adding these margins would not alter the key mechanisms discussed in this paper.

That human capital is at least in part tied to a worker’s specific occupation, or the tasks performed in them, has been documented in several empirical studies, for instance in Cortes and Gallipoli (2018), Gathmann and Schönberg (2010), Kambourov and Manovskii (2009b), and Sullivan (2010). Two recent quantitative models of polarization, Dvorkin and Monge-Naranjo (2019) and Kikuchi and Kitao (2020), include occupation-specific capital in their analysis. While Dvorkin and Monge-Naranjo (2019) do not model a consumption-saving choice, precluding the mechanism proposed here, Kikuchi and Kitao (2020) model such a choice and obtain an endogenous wealth distribution as I do. The focus of their study, however, lies on the welfare effects of labor market polarization on different age and skill groups, and not on analysing the interaction between incomplete asset markets and occupational choices. Since they do not display the share of households that are hand-to-mouth in their paper, it is difficult to assess how quantitatively important this distortion is in their model. Also, they assume wages to be exogenous, while all factor prices are endogenous in my model.

⁷I further deviate from vom Lehn (2020) in that I assume that households differ ex ante only in general skill type. In vom Lehn (2020), households draw three additional skill types, one for each occupation.

The idea that hand-to-mouth households matter greatly for the propagation of macroeconomic shocks has recently been addressed by several papers. Aguiar et al. (2020) and Kaplan, Violante, et al. (2014) present empirical evidence that at least 30% of US households live hand-to-mouth, i.e. own very few liquid assets. The former, as well as Fagereng et al. (2020), also show that hand-to-mouth households display large marginal propensities to consume, which is in line with the implications of theoretical models of the consumption-saving choice for households that are not on the Euler equation. A detailed depiction of the wealth distribution, including the existence of a large share of hand-to-mouth households, has been shown to affect the transmission of different macroeconomic shocks (e.g. monetary policy shocks (Kaplan, Moll, et al., 2018), or fiscal policy shocks (Hagedorn et al., 2019)), but to the best of my knowledge not yet in the context of technological change and occupational mobility.

2 Empirical Evidence

In this section, I first summarize the concept of labor market polarization and introduce the three broad occupational groups, as defined in earlier studies (Autor and Dorn, 2013; Jaimovich and Siu, 2020). I then analyse the liquid asset holdings of households using data from the SCF. I highlight that both workers who work in routine occupations as well as those that are relatively young are hand-to-mouth with a higher probability than the average US household. This is important as these two groups of households play a crucial role during the labor market transition to an economy with less demand for routine labor.

2.1 Labor market polarization and broad occupational groups

To describe the phenomenon of labor market polarization, Autor and Dorn (2013) first order 318 detailed occupations according to their skill level, which they proxy by the average hourly wage earned in the occupation in 1980. They show that between 1980 and 2005 occupations at the bottom and at the top of the skill distribution gained both in terms of employment share, and in terms of wages relative to occupations found in the centre of the skill distribution (cf. their Figure 1).

Autor and Dorn (2013) then scrutinize the task content of each single occupation using the US Department of Labor’s Dictionary of Occupational Titles. They divide occupations into six groups and highlight the main tasks performed in them. For tractability, the literature then commonly subsumes these further into three broad occupational groups (Jaimovich and Siu, 2020; vom Lehn, 2020).⁸ While there certainly exist some cases of ambiguity when assigning the occupations into these three groups, the proposed assignment is complete and

⁸Following Jaimovich and Siu (2020), the services occupations are the only occupations I categorize as manual. See Appendix A for details.

mutually exclusive. This implies that each of the detailed occupations is considered to be part of exactly one of the three broad groups.

The first group of occupations are intensive in **manual** tasks, i.e. they require eye-hand-foot coordination, adapting to new surroundings often, and (non-trivial) interaction with other humans. These occupations can be found at the bottom of the skill distribution and are typically service occupations. Examples for manual occupations are bus drivers, waiters and waitresses, door-to-door/street sales, health and nursing aides, or janitors and gardeners.⁹

The second group consists of occupations that intensively require **routine** tasks to be performed, i.e. calculations, record-keeping, repetitive customer service, repetitive assembly, picking or sorting. These occupations are precisely the ones often found in the middle of the skill distribution, whose employment shares and relative wages have fallen compared to the other two occupational groups. Typical examples of routine occupations are bookkeepers, accounting clerks, secretaries, bank tellers, as well as machine operators and assemblers or butchers and meat cutters.¹⁰

Occupations of the third group require **abstract** tasks, i.e. cognitive thinking, forming/testing hypotheses, persuading, managing or organizing. These kind of jobs are found in the high-skill occupations, and typical examples include police and detectives, public service, fire fighting, prevention and inspection, school teachers, engineers and managers.

The term “polarization” refers to the fact that the occupational wage and employment distributions have shifted towards their poles since the 1980s, while the middle of these distributions, where many of the routine occupations are found, has “hollowed out”. The share of hours worked in the routine occupations fell from 58.5% in 1980 to 46.2% in 2005, while it increased from 31.6% to 40.9% in the abstract, and from 9.9% to 12.9% in the manual occupations (Autor and Dorn, 2013). One commonly cited cause for the decline of the routine occupations is technological change that substitutes for routine labor (Autor, Levy, et al., 2003; Jaimovich, Saporta-Eksten, et al., 2020; vom Lehn, 2020). The fact that capital, most prominently ICT capital, has become much cheaper over the recent decades has led to a replacement of tasks formerly performed by humans with machines. Manual and abstract tasks are not so easily substitutable by this kind of technological change, as they require either non-trivial interaction with humans or tasks such as managing and organising, all of which machines struggle to excel at.

⁹For an extensive treatment of the classification procedure and more examples for occupations, also refer to Autor, Levy, et al. (2003).

¹⁰Some studies make a further distinction between routine manual and routine abstract tasks and occupations. I abstract from this further division for simplicity.

2.2 Hand-to-mouth households

The next sections will emphasize that the occupational choices of workers who are at an interior solution of their consumption-savings problem can differ from those who are exogenously prevented from borrowing (as in the simplified model in Section 3) or who optimally choose to be hand-to-mouth (as in the full model in Section 4). In this section, I demonstrate that being hand-to-mouth, i.e. holding either no (or very few) liquid assets or being close to the borrowing constraint, is a very relevant state for both groups of households along which the labor market transition of the recent decades has taken place: the routine workers and the inexperienced workers arriving new to the labor market.

For the analysis, I use the Survey of Consumer Finances, which is a US household survey with a focus on acquiring accurate information regarding the participating households' wealth holdings. I use twelve waves, from 1989 to 2019. In terms of sample selection and classifying households as either "hand-to-mouth" or not, I follow Kaplan, Violante, et al. (2014). In particular, I consider all households whose head is between 22 and 79 years old, and discard those who report negative labor income, and those whose only positive income stems from self-employment.

I then relate each household's liquid assets to its current income, and classify it as hand-to-mouth if liquid asset holdings are either zero (or positive and close to zero), or if liquid asset holdings are close to an imputed borrowing constraint, equal to one times monthly income. Appendix A lays out the details.

To obtain the shares of hand-to-mouth households by broad occupational group, I also need to assign the households into the three groups. Data on occupations is very sparsely coded in the SCF, with the publicly available files only containing information on whether the household is working in one of six relatively coarsely defined groups of occupations. However, luckily, there exists a substantial overlap between the groups of occupations formed in the SCF and those used in Autor and Dorn (2013). To demonstrate that I am able to map the two definitions relatively well, Figure 1 plots the shares of employment obtained from both the SCF next to those provided by Autor and Dorn (2013). While I am overestimating (underestimating) slightly the share of workers employed in routine (abstract) occupations in the early 1990s, the time series are relatively closely aligned towards the early 2000s. Appendix A details the mapping between occupations in the SCF and the three broad occupational groups used in my analysis.

Figure 2 plots the shares of households that I classify as being hand-to-mouth separately for each broad occupational group as well as unconditionally for all households.¹¹ Two results stand out. First, there is a clear ordering of hand-to-mouth shares by occupational group, with workers in the manual occupations most likely to be hand-to-mouth, and abstract

¹¹Figures 24 and 25 in the appendix contain versions of Figures 2 and 3 with 95% confidence intervals. "All households" refers to all households in the sample conditional on its head being employed. Results when considering all households regardless of working status, are very similar.

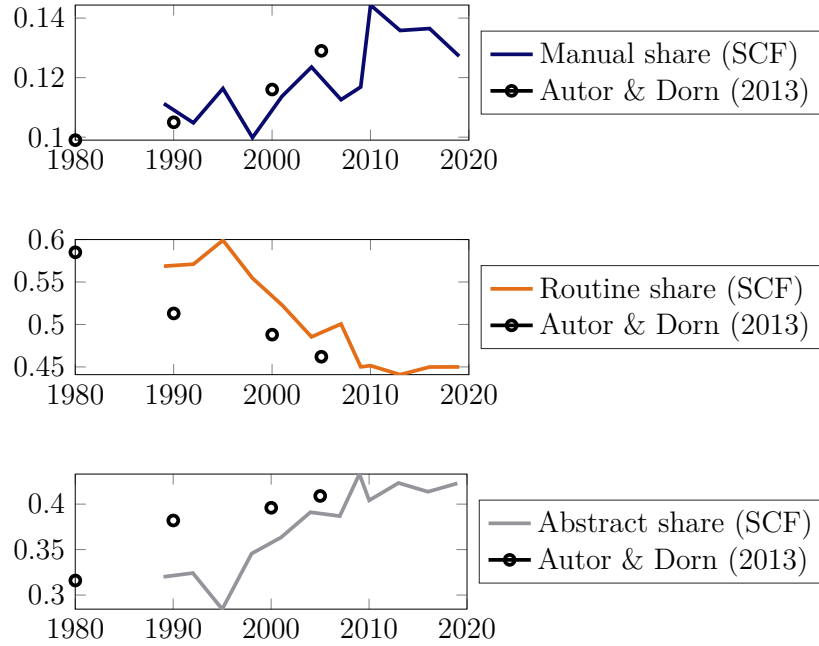


Figure 1: Employment shares in the SCF and in Autor and Dorn (2013).

workers least likely. This is perhaps not surprising, given that abstract workers are usually the ones earning the highest incomes, manual workers earning the lowest incomes, and routine workers in between.

Second, routine workers, while not as likely as manual workers to be hand-to-mouth, are still more likely to be so than the average US household. Across all years, the probability of routine workers to be hand-to-mouth was on average 34%, higher than the average probability across all households of 29%. At each single point in time, the two series differ by three to seven percentage points. Given that the manual occupations group is by far the smallest of the three groups in terms of employment share, this also implies that conditional on drawing a random hand-to-mouth household head, there was a 65% chance of her working in a routine occupation in the late 1980s, while today the probability is still slightly above 50%.

In Appendix D, I further document that the high share of hand-to-mouth households among the routine workers is driven to a large extent by the high prevalence of wealthy hand-to-mouth households among them. These are households who are by definition hand-to-mouth, but own positive illiquid wealth such as equity in houses or indirect stock holdings. In all years between 1995 and 2016, routine workers were more likely to be wealthy hand-to-mouth than either abstract or manual workers.

The SCF provides no information regarding the tenure, or years of work, of workers in their current occupation. In order to gauge whether inexperienced labor market entrants, who are arguably not yet as tightly attached to their occupation as workers with a lot of experience, are likely to be hand-to-mouth, I am therefore left to proxy occupational experience with age. That age is an important determinant of being hand-to-mouth, however, has already been noted by Kaplan, Violante, et al. (2014). For completeness, I therefore only

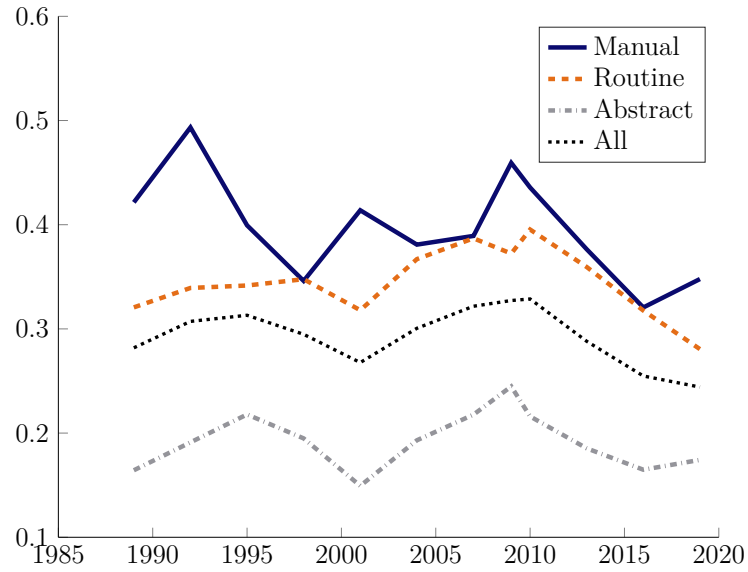


Figure 2: Hand-to-mouth shares in the three broad occupational groups.

report in Figure 3 that household heads younger than 40 years are more likely to be hand-to-mouth than those who are older. In addition, and as was to be expected, young routine workers are even more likely to be hand-to-mouth than young households on average. For further details on the age characteristics of hand-to-mouth households I refer the reader to Kaplan, Violante, et al. (2014).

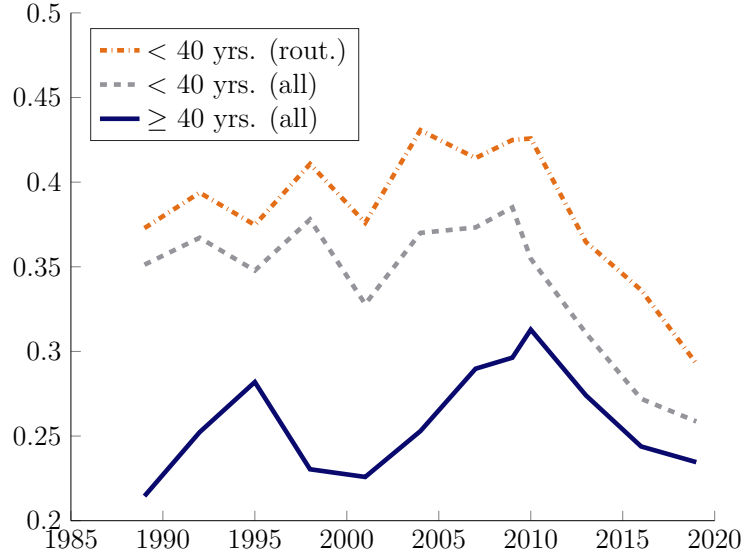


Figure 3: Hand-to-mouth shares by age of household head.

Notes: (all) corresponds to households employed in any of the three broad occupational groups, (rout.) only to those employed in routine occupations.

3 A small model of dynamic occupational choice

In this section I illustrate the core mechanism at work in the full model of Section 4. I highlight that in a dynamic setting, in which relative wages between occupations change over time, households make differing occupational choices depending on whether they are hand-to-mouth or not. This is true only, however, if there is some part of human capital that is occupation-specific, as only then the occupational choice becomes a dynamic investment decision. In contrast to the full model of Section 4, being hand-to-mouth is not a choice of the household in the simple model proposed here, but an exogenously given attribute.

3.1 Intuition

To fix ideas, think about two occupations, routine and abstract, and two time periods. Suppose, as is shown in the left panel of Figure 4, that in period 1 the wage of the abstract occupation is lower than in the routine occupation and vice versa in period two.

Suppose first that there exists no occupation-specific human capital, and income of household working in occupation j is $y_t = w_{j,t}$. In this case, the occupational choices in both time periods are simple and the same for every household: choose the occupation whose wage is higher in each time period.

This changes in the presence of occupation-specific human capital. Assuming that income is $y_t = h_{j,t} \cdot w_{j,t}$, where $h_{j,t}$ is human capital in occupation j , the occupational choice in period one becomes a dynamic investment decision. Consider a household who has not accumulated any human capital yet in period one, e.g. a new labor market entrant with $h = \underline{h} = 1$. Under certain paths for wages w_{abstract} and w_{routine} , a household who maximises lifetime income



Figure 4: Wage paths

using her occupational choices might choose the abstract occupation already in period one if that entails her being an experienced household in the abstract occupation in period two. A household consuming current income however, is more attracted to staying in the routine occupation in period one, taking advantage of the still higher wage there.

The logic is similar for a household who is experienced in the routine occupation in period one, i.e. has accumulated human capital $h = \bar{h} > 1$ in the routine occupation. This case is depicted in the right panel of Figure 4. The fall in earnings caused by a switch to the abstract occupation in period one is especially unattractive for households who consume their current income. If households can freely borrow against future income, however, switching to the abstract occupation in period one can be the optimal strategy. The following two-period model formalises these points.

3.2 Two-period model

There are two periods, 1 and 2. Households arrive at period one with prior occupation $j \in \{r, a\}$. They have accumulated occupation-specific human capital $h \in \{\underline{h}, \bar{h}\}$ in this prior occupation, with $\underline{h} < \bar{h}$. Human capital in the respectively other occupation is always implicitly \underline{h} , which is why only human capital in the current occupation is a state variable. If an experienced household (\bar{h}) switches the occupation, her human capital is reset to \underline{h} .

Inexperienced households become experienced in period two with certainty, unless they switch occupations at the beginning of period two. Income of the households is $y = w_j h$, and they discount the future by a factor $\beta \in (0, 1)$. The routine wage is normalized to one in both periods, i.e. $w_{r,t=1} = w_{r,t=2} = 1$. The abstract wages are $w_{a,t=1} = \frac{1}{\omega}$ and $w_{a,t=2} = \omega$, with $\omega > 1$. This implies that wage paths resemble those depicted in Figure 4.

There are two types of household, one who can freely borrow against future income, and one who is exogenously hand-to-mouth and consumes her current income.¹² The respective problems of the households with state (j, h) are:

¹²Households consume their current income by assumption. As will become clear momentarily, this choice could be endogenized by assuming, for instance, a borrowing constraint of $\underline{b} = 0$.

Unconstrained

$$\begin{aligned} & \max_{c_1, c_2, j_1, j_2} \ln c_1 + \beta \ln c_2 \\ \text{s.t.: } & c_1 + \frac{c_2}{1+r} = y_1 + \frac{y_2}{1+r} \equiv y_L \end{aligned}$$

Hand-to-mouth

$$\begin{aligned} & \max_{c_1, c_2, j_1, j_2} \ln c_1 + \beta \ln c_2 \\ \text{s.t.: } & c_1 = y_1, \quad c_2 = y_2 \end{aligned}$$

where r is the exogenous interest rate, c denotes consumption, and j_t is the occupational choice in period t .

3.2.1 Inexperienced worker

Consider first a worker with $h = \underline{h}$ who is not yet attached to any occupation, i.e. $j \in \{r, a\}$. What are the optimal occupational choices for the two types of households, especially in period one? Given that the household can choose between the two occupations in both periods there exist four possible combinations of occupational choices, which in turn determine labor income:

1. $\{j_1 = r, j_2 = r\} \rightarrow \{y_1 = \underline{h}, y_2 = \bar{h}\} \rightarrow \{y_L = \underline{h} + \frac{1}{1+r}\bar{h}\}$
2. $\{j_1 = r, j_2 = a\} \rightarrow \{y_1 = \underline{h}, y_2 = \omega \underline{h}\} \rightarrow \{y_L = \underline{h} + \frac{\omega}{1+r}\underline{h}\}$
3. $\{j_1 = a, j_2 = a\} \rightarrow \{y_1 = \underline{h}/\omega, y_2 = \omega \bar{h}\} \rightarrow \{y_L = \underline{h}/\omega + \frac{\omega}{1+r}\bar{h}\}$
4. $\{j_1 = a, j_2 = r\}$ dominated by 2.

The following result holds regarding the occupational choice in the first period. All proofs are relegated to Appendix B.

Proposition 1. *In $t = 1$, unconstrained households choose the abstract occupation iff*

$$1 + r \leq \omega(\bar{h}/\underline{h} - 1) \min \left\{ \frac{\bar{h}/\underline{h}}{\bar{h}/\underline{h} - 1}, \frac{\omega}{\omega - 1} \right\}.$$

In this case, unconstrained households are net borrowers in $t = 1$.

Hand-to-mouth households never choose the abstract occupation in $t = 1$.

This very simple example shows that there exists a set of parameter combinations under which the unconstrained household optimally chooses option 3. This means that she begins her work life in the abstract occupation, even though wages are still higher in the routine occupation. As a consequence, she borrows against future income in period one.

The condition in Proposition 1 becomes more likely to hold when the interest rate r is low, such that borrowing against future income is cheap, and when the human capital spread \bar{h}/\underline{h} is large, such that starting to gain experience in the abstract occupation already today is valuable. In contrast, a higher ω has an ambiguous effect on the switching decision. This is due to the non-linear way in which it affects earnings in period one and in period two in opposite directions.

The second part of Proposition 1 tells us that under no combination of parameters will the hand-to-mouth household work in the abstract occupation in the first period. The intuition is simple: Foregoing the high wages in the routine occupations today is too costly, and if wages are very high in the abstract occupations in period two, she can still switch to those occupations at a later point. Another way to understand this result is to note that whenever parameters are such that unconstrained households choose option 3, their income is higher in the second period. This implies that they become borrowers in period one, which hand-to-mouth households are prevented from doing by assumption.¹³

3.2.2 Experienced routine worker

Consider now a worker priorly employed in the routine occupations, i.e. with $j = r$ and $h = \bar{h}$. The potential occupational choices are:

1. $\{j_1 = r, j_2 = r\} \rightarrow \{y_1 = \bar{h}, y_2 = \bar{h}\} \rightarrow \{y_L = \bar{h} + \frac{1}{1+r}\bar{h}\}$
2. $\{j_1 = r, j_2 = a\} \rightarrow \{y_1 = \bar{h}, y_2 = \omega \underline{h}\} \rightarrow \{y_L = \bar{h} + \frac{\omega}{1+r}\underline{h}\}$
3. $\{j_1 = a, j_2 = a\} \rightarrow \{y_1 = \underline{h}/\omega, y_2 = \omega \bar{h}\} \rightarrow \{y_L = \underline{h}/\omega + \frac{\omega}{1+r}\bar{h}\}$
4. $\{j_1 = a, j_2 = r\}$ dominated by 2.

Proposition 2. *In $t = 1$, unconstrained households switch to the abstract occupation iff*

$$1 + r \leq \omega - \frac{\max\{\omega, \bar{h}/\underline{h}\} - 1}{\bar{h}/\underline{h} - 1/\omega}$$

In this case, unconstrained households are net borrowers in $t = 1$.

Hand-to-mouth households never choose the abstract occupation in $t = 1$.

The result resembles the previous one for the inexperienced worker. This was to be expected: the only difference in the case of the experienced routine worker is that choosing the abstract occupation in period one is even more costly because of the already accumulated occupation-specific human capital. This also explains why a growing human capital spread \bar{h}/\underline{h} does not unambiguously make the condition in Proposition 2 more likely to hold (like

¹³This theoretical result is in line with empirical evidence on initial job decisions of college students. Luo and Mongey (2019) and Rothstein and Rouse (2011) show that college graduates with high levels of debt subsequently choose work that offers higher wages (but lower levels of job satisfaction or amenities). Gervais and Ziebarth (2019) corroborate this result for a representative sample of undergraduate students who received their bachelors degree, and show in addition that debt reduces the likelihood of attending graduate school. (These results are not uncontested. For instance, Ji (2021) finds that college students with debt end up with lower-paid jobs. See his paper and Luo and Mongey (2019) for a discussion.) Minicozzi (2005) finds that the expected log of initial wage rises and expected four year wage growth declines with educational debt. These are precisely the wage dynamics predicted by the simplified model for hand-to-mouth households.

it did in Proposition 1), as it further raises the cost of leaving the routine occupation.¹⁴ As was the case for inexperienced workers, experienced workers who are hand-to-mouth never choose the abstract occupation in period one.

The simple model of this section was meant to illustrate the core mechanism at work in the full model of the next section. Of course, being hand-to-mouth is usually a choice made by households. Rational households, who have perfect foresight over future wage paths, could save up buffers of assets in order to make the income-maximising occupational choices at any point in time in the future. A more sophisticated model, which endogenizes the wealth distribution and therefore hand-to-mouth status, is necessary to judge whether the friction proposed so far has had meaningful implications for aggregate variables during the period of labor market polarization in the recent decades.¹⁵

In a full-fledged incomplete markets model, like the one presented in the next section, every household understands that she might be facing a borrowing constraint (or a borrowing wedge) at some point in the future, even if today she has accumulated a large amount of assets. This implies that every household, even those some distance away from the borrowing constraints, will have a tendency to work in the routine occupations for a relatively long time. Put differently, while this section provided a stark difference between “hand-to-mouth” and “not hand-to-mouth” households, in the full model every household acts to some degree as if they were “hand-to-mouth”.

4 Model

This section presents the full model. Time t is continuous and runs forever. The economy consists of a representative firm, households and a government. The representative firm operates under perfect competition and produces using capital and labor from three occupations (manual, routine abstract). Households are subject to uninsurable idiosyncratic labor income risk, in the spirit of Aiyagari (1994), Bewley (1983), and Huggett (1993). The government taxes households and distributes transfers to them. The analysis takes place in general equilibrium, i.e. all factor prices are endogenous. The exogenous driver of technological change is a falling relative price of ICT capital $\frac{1}{q_{ict}}$. I assume that the economy is initially in its steady state in 1980 with a constant q_{ict} . It is then hit by a shock that raises q_{ict} over many years to a new, higher level, until the economy reaches a new steady state. Agents have perfect foresight over the path of q_{ict} once it is revealed in 1980.

¹⁴Figure 28 in the appendix visualizes the occupational choices for the unconstrained households for a net interest rate of $r = 10\%$.

¹⁵Section B.2 in the appendix contains an extension of the basic model presented here, introducing a variable that captures mean-reverting productivity. This extended model can qualitatively account for the fact that a higher share of households exits the routine occupations during a recession (because the opportunity costs of doing so are smaller than during a boom). This is in line with empirical evidence presented in Hershbein and Kahn (2018) and Jaimovich and Siu (2020).

4.1 Representative firm

The final good in the economy Y_t is produced according to a multiply nested constant elasticity of substitution production function (vom Lehn, 2020):

$$Y_t = \underbrace{K_{s,t}^\alpha}_{\text{Non-ICT capital}} \left[\mu_m N_{m,t}^{\frac{\gamma_m-1}{\gamma_m}} + (1 - \mu_m) \left[\mu_a N_{a,t}^{\frac{\gamma_a-1}{\gamma_a}} + (1 - \mu_a) R_t^{\frac{\gamma_a-1}{\gamma_a}} \right]^{\frac{\gamma_a(\gamma_m-1)}{(\gamma_a-1)\gamma_m}} \right]^{\frac{\gamma_m(1-\alpha)}{\gamma_m-1}} \quad (1)$$

where

$$R_t = \left[(1 - \mu_r) \underbrace{K_{ict,t}^{\frac{\gamma_r-1}{\gamma_r}}}_{\text{ICT capital}} + \mu_r N_{r,t}^{\frac{\gamma_r-1}{\gamma_r}} \right]^{\frac{\gamma_r}{\gamma_r-1}}$$

Here, $N_{j,t}$ denotes effective labor employed in occupation $j \in \{m, r, a\}$.

There are two types of capital: ICT capital and all remaining capital in the economy, for instance structures. The laws of motion for the two types of capital are, respectively,

$$\begin{aligned} \dot{K}_{ict,t} &= q_{ict,t} I_{ict,t} - \delta_{ict} K_{ict,t} \\ \dot{K}_{s,t} &= q_{s,t} I_{s,t} - \delta_s K_{s,t} , \end{aligned}$$

where $q_{x,t}$ denotes the amount of capital x that can be purchased for one unit of output at time t (Greenwood et al., 1997). The price of the final good is normalized to one. The parameters δ_x capture depreciation of the capital stock.

All factor inputs are paid their marginal products and the firm makes zero profits because of the assumption of constant returns to scale. The first order conditions of the firm's profit maximization problem are listed in Appendix C.1.

Crucially, an increase in q_{ict} , i.e. a falling relative price of ICT capital, will be the exogenous driving force of labor market polarization later on. To see that a rise in q_{ict} can be interpreted as (factor-augmenting) technological change, one can slightly rewrite the production function. First, define capital expressed in terms of the final good as $\tilde{K}_x = K_x/q_x$. Then, one can rewrite (1) as

$$Y_t = (q_{s,t} \tilde{K}_{s,t})^\alpha \left[\mu_m N_{m,t}^{\frac{\gamma_m-1}{\gamma_m}} + (1 - \mu_m) \left[\mu_a N_{a,t}^{\frac{\gamma_a-1}{\gamma_a}} + (1 - \mu_a) R_t^{\frac{\gamma_a-1}{\gamma_a}} \right]^{\frac{\gamma_a(\gamma_m-1)}{(\gamma_a-1)\gamma_m}} \right]^{\frac{\gamma_m(1-\alpha)}{\gamma_m-1}}$$

with

$$R_t = \left[(1 - \mu_r) (q_{ict,t} \tilde{K}_{ict,t})^{\frac{\gamma_r-1}{\gamma_r}} + \mu_r N_{r,t}^{\frac{\gamma_r-1}{\gamma_r}} \right]^{\frac{\gamma_r}{\gamma_r-1}}$$

and the laws of motion for capital can be rewritten as

$$\dot{\tilde{K}}_{x,t} = I_{x,t} - (\delta_x + \gamma_{q_{x,t}}) \tilde{K}_{x,t} .$$

where $\gamma_{q_{x,t}} = \dot{q}_{x,t}/q_{x,t}$.

4.2 Households

There exists a continuum of mass one of households who value consumption c_t and dislike labor ℓ_t . Households are ex-ante heterogeneous and characterized by their fixed skill type s . They discount the future at rate ρ and die at rate ζ . Expected lifetime utility of a household living at time T is

$$U_T(\{c_t, \ell_t\}) = \mathbb{E} \int_{t=T}^{\infty} e^{-(\rho+\zeta)(t-T)} u(c_t, \ell_t) dt$$

where $u(c, \ell)$ is the flow utility function, which 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 $\lim_{\ell \rightarrow 0} u_\ell(c, \ell) = 0$ and $\lim_{c \rightarrow 0} u_c(c, \ell) = \infty$.

Households can save in two assets, a liquid asset b and an illiquid asset \tilde{k} . The modelling of these assets and the household's portfolio problem follows Kaplan, Moll, et al. (2018). Like them, I also assume that households who die are replaced by new-born households who own zero assets.¹⁶

The liquid asset is provided by the government, and households can borrow in this asset up to a borrowing constraint \underline{b} . To help generate a realistic amount of households who live hand-to-mouth I assume the existence of a borrowing wedge $\kappa > 0$, i.e. borrowing is possible only at a higher interest rate than lending in b . The interest rate on liquid assets is therefore

$$r_{b,t}(b) = r_{b,t} + \kappa \mathbf{1}\{b < 0\}$$

The illiquid asset is subject to a portfolio adjustment cost $\chi(\tilde{k}, d)$. Positive d denote a deposit, negative d a withdrawal of wealth from the illiquid account.

Labor income Households optimally choose to work in one of the three broad occupational groups at each instant of time. Denote their occupational choice by $j \in \{m, r, a\}$. Their (pre-tax) labor income y consists of five components:

$$y = w_j \cdot \ell \cdot z \cdot h \cdot \phi_j(s) .$$

The first component, w_j , denotes the wage per efficiency unit in occupation j . The intensive labor supply decision is captured by ℓ . The term z captures the idiosyncratic productivity component of labor income, which I assume to be unaffected by occupational choices of the household. It represents uninsurable labor income risk and its natural logarithm \hat{z} evolves according to some stochastic process

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

Occupation-specific human capital in the current occupation j is captured by h . It can take on two values, capturing whether the worker is inexperienced (\underline{h}) or experienced (\bar{h}),

¹⁶The accidental bequests of dying households are passed on to all living households in proportion to their current assets.

with $\bar{h} > \underline{h}$. For tractability I assume that households can only be experienced (\bar{h}) in their current occupation. Once a household leaves her current occupation and switches to another one, h is set to \underline{h} . This implies that only human capital in the current occupation is a state variable, as human capital in the respectively other two occupations is always implicitly \underline{h} . It also implies that there is no recall of human capital if a worker ever returns to one of her previous occupations.¹⁷ I assume that inexperienced households become experienced with Poisson intensity λ_h , and that experienced households never become inexperienced unless they choose to switch the occupation. New-born households are inexperienced (\underline{h}), of the same skill type s as the household they are replacing, and draw from the invariant stationary distribution of z at the beginning of their lives.

The mechanism that gives rise to the endogenous sorting of workers into occupational groups is modelled as in Cortes (2016), Jung and Mercenier (2014), and vom Lehn (2020). The term $\phi_j(s)$ defines how productive a household of skill type s is in occupation j . I assume that higher skill types have a comparative advantage in the abstract occupations, and lower skill types a comparative advantage in the manual occupations. In particular, in line with the previous literature I assume that occupational production functions are log-linear in skill:

$$\phi_j(s) = \exp(a_j s), \text{ with } 0 = a_m < a_r < a_a .$$

Importantly, every household can potentially work in any of the three occupational groups. However, given the functional form assumptions, low skill types optimally choose manual occupations, medium skill types routine occupations, and high skill types the abstract occupations. This is visualized in Figure 5, which depicts the optimal occupational choices in steady state. For an equilibrium with positive labor supply in each of the occupations to exist, wages w_j must be ordered as can be seen on the y-axis.¹⁸ The dashed extensions of the solid lines represent the hypothetical earnings of a household, were she to work in one of the other occupations.

In sum, these assumptions imply that there is no occupational mobility in the steady state of the model. The occupational choice is determined unambiguously by the skill type s of the household. This skill type, however, is fixed over the lifetime, so that the household never wishes to switch to another occupation. Accordingly, skill types with $s \leq \underline{s}$ work in manual occupations, those with $\underline{s} < s < \bar{s}$ are routine workers, and those with $s \geq \bar{s}$ work in the abstract occupations. I discuss this simplification further below.

Occupational mobility does potentially occur, however, during the transition to a new steady state which features a lower share of routine labor, i.e. when labor markets polarize.

¹⁷This is a common simplification in the literature (Kambourov and Manovskii, 2009a; Kikuchi and Kitao, 2020).

¹⁸For instance, if it were the case that $\log(w_m) < \log(w_r)$, no household would choose to work in the manual occupations. To simplify the exposition, the visualized ordering implicitly assumes that $s > 0$, which will not be the case in the calibrated model in which I assume that $s \sim N(0,1)$. However, in that case, too, a necessary ordering of wages exists for there to be positive labor supply in each occupation.

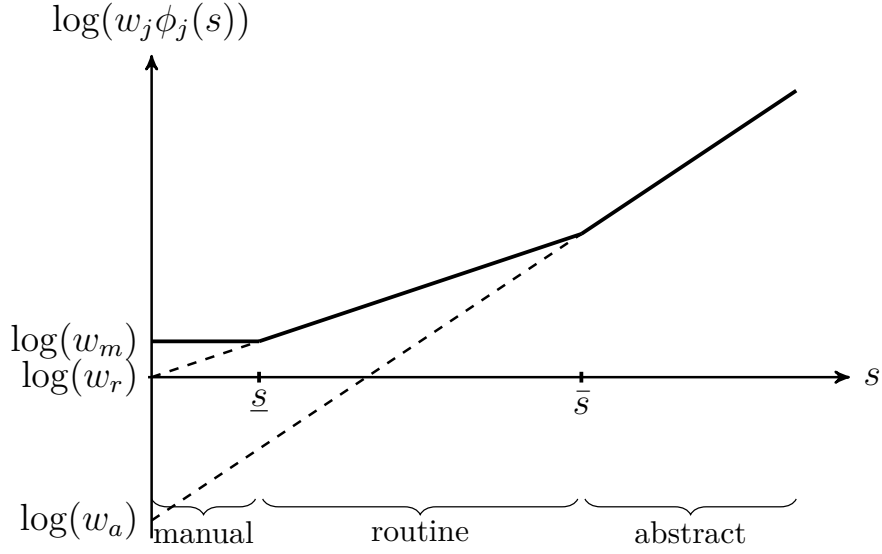


Figure 5: Skills and wages before polarization

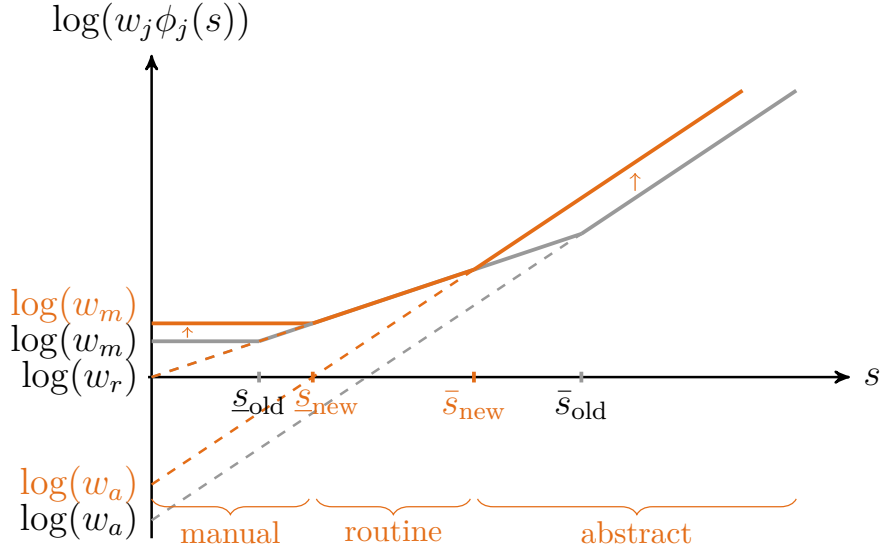


Figure 6: Skills and wages after polarization

This is visualized in Figure 6. An increase in q_{ict} will, given the calibrated parameters of the production function, endogenously raise the wages of manual and abstract occupations relative to the routine occupations. This shifts the skill cut-offs \underline{s} and \bar{s} inward, leading to a smaller set of skill types who optimally choose the routine occupations in the new steady state.

During the transition to the new steady state, the reallocation of skill types over occupational groups changes due to the two margins of adjustment discussed in the beginning. First, households who die are replaced by households of the same skill type s but without occupational tenure, i.e. $h = \underline{h}$. Consequently, they have no attachment to any occupation that would impact on their occupational choice. Households of skill type $s \in [\underline{s}_{old}, \underline{s}_{new}]$, who chose routine occupations before the labor market polarization, realize that manual

occupations become increasingly attractive for them as w_m rises relative to w_r . They might therefore choose to work in the manual occupations when they enter the labor market. The logic is analogous for new labor market entrants with $s \in [\bar{s}_{\text{new}}, \bar{s}_{\text{old}}]$, who will increasingly turn to the abstract occupations.

Second, experienced routine households, i.e. with \bar{h} , with skill types in either of the two discussed regions, might consider switching to a new occupation as relative wages keep changing in favor of manual and abstract occupations. For them, however, switching the occupation is more unattractive than for inexperienced workers, as it comes with a loss of human capital from \bar{h} to \underline{h} . As becomes clear visually, the incentive to switch is highest for those skill types closest to the old cut-offs, $\underline{s}_{\text{old}}$ and \bar{s}_{old} , as for them switching yields the highest wage gain.

That the model implies no occupational mobility in steady state is clearly an abstraction.¹⁹ One could explicitly account for it by introducing additional shocks, like an “exit shock” that forces a household to work in another occupation, or additional productivity shocks on the occupational level that make workers switch endogenously. I choose not add these additional shocks as this allows me to focus on the excess mobility caused by labor market polarization, and because it makes solving the model computationally feasible.²⁰

Household problem Equation (2) shows the household problem.

$$\begin{aligned} \max_{c_t, \ell_t, j_t, d_t} U_T(\{c_t, \ell_t\}) & \tag{2} \\ \text{subj. to:} & \\ \dot{b}_t = (1 - \tau_t)w_{j,t}\ell_t z_t h_t \phi_j(s) + r_{b,t}(b)b_t - \chi(d_t, \tilde{k}_t) - d_t + T_t - c_t & \\ \dot{\tilde{k}}_t = r_{k,t}\tilde{k}_t + d_t & \\ b_t \geq -\underline{b}, \tilde{k}_t \geq 0 & \end{aligned}$$

T_t denotes a lump-sum transfer from the government, while τ_t denotes a proportional labor income tax. As before, I define $\tilde{k}_t \equiv \frac{k_{ict,t}}{q_{ict,t}} + \frac{k_{s,t}}{q_{s,t}}$ to denote capital in units of the final good. The household problem gives rise to a Hamilton-Jacobi-Bellman equation, which is relegated to Appendix C.2. The interest rate r_k on \tilde{k} , as well as a no-arbitrage condition, which ensures that households are indifferent between holding either type of capital (ICT and non-ICT),

¹⁹Kambourov and Manovskii (2008) report that workers change their 1-digit occupation with an annual probability of 11%. The three broad occupational groups used here each comprise several of these 1-digit occupations.

²⁰One could, however, think of movements between occupations as implicitly captured by fluctuations in the idiosyncratic earnings component z , as long as workers are still inexperienced (\underline{h}). Only when households have become experienced (\bar{h}) does it not make sense any longer to think of them as moving between different occupational groups, as the model would imply that they lose their human capital. Gervais, Jaimovich, et al. (2016) provide evidence that occupational mobility drastically decreases in age. This lends credibility to an interpretation of the model in which occupational mobility implicitly takes place among the inexperienced.

are, respectively,

$$r_{k,t} \equiv q_{ict,t} r_{ict,t} - (\delta_{ict} + \gamma_{q_{ict,t}}) = q_{s,t} r_{s,t} - (\delta_s + \gamma_{q_{s,t}}). \quad (3)$$

4.3 Government

The government budget constraint holds at each instant of time:

$$G_t + T_t + r_{b,t} B_t = \tau \int_i y_i d\Gamma_t(i). \quad (4)$$

Here, G_t denotes government spending, and B_t the government bond supply.

All idiosyncratic state variables of the households ($\{s, z, j, h, b, \tilde{k}\}$) are collected in i , and $\Gamma(i)$ denotes the cumulative distribution function over the household state space.²¹

4.4 Equilibrium

An equilibrium is defined as paths for household decisions $\{a_t, b_t, d_t, c_t, \ell_t, j_t\}_{t \geq 0}$, input prices $\{w_{m,t}, w_{r,t}, w_{a,t}, r_{ict,t}, r_{s,t}, r_{b,t}\}_{t \geq 0}$, government transfers $\{T_t\}_{t \geq 0}$, distributions $\{\Gamma_t\}_{t \geq 0}$, and aggregate quantities such that, at every t :

1. Given prices, aggregate quantities, the distribution $\{\Gamma_t\}_{t \geq 0}$, and the stochastic processes for individual states, policy functions c^* , ℓ^* , b^* , \tilde{k}^* and j^* solve the households' problem (2).
2. The representative firm optimizes, given input prices. The FOCs (6), (7), (8), (9), and (10) hold.
3. The government budget constraint (4) holds.
4. The labor markets clear, i.e. for $j \in \{m, r, a\}$:

$$N_{j,t} = \int_{i:j^*=j} z_t h_t \ell_t^* \phi_j(s) d\Gamma_t(i)$$

5. The no-arbitrage condition (3) holds and the capital market clears:

$$\tilde{K}_t \equiv \tilde{K}_{ict,t} + \tilde{K}_{s,t} = \int_i \tilde{k}_t^* d\Gamma_t(i)$$

6. The government bond market clears:

$$B_t = \int_i b_t^* d\Gamma_t(i)$$

²¹Following the discussion above, the occupational j is a redundant state variable in steady state, as the skill type s perfectly predicts occupational choices. Only during the transition between steady states j might differ for households of the same skill type.

7. The resource constraint holds:

$$Y_t = C_t + I_{s,t} + I_{ict,t} + G_t + \int_i \chi(\cdot) + \kappa \max\{-b, 0\} d\Gamma_t(i)$$

where C_t denotes aggregate consumption.

8. The sequence of distributions satisfies aggregate consistency conditions.

4.5 Calibration

4.5.1 External calibration

I set the first set of parameters as in Kaplan, Moll, et al. (2018). The utility function is

$$u(c, \ell) = \log(c) - \varphi \frac{\ell^{1+\gamma}}{1+\gamma},$$

where γ is set to 1, and φ to 2.2. These choices ensure 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 (\$16,500). The portfolio adjustment cost function for the illiquid asset \tilde{k} is a convex adjustment cost function

$$\chi(d, \tilde{k}) = \chi_0 + \chi_1 |d/\tilde{k}|^{\chi_2} \tilde{k},$$

where χ_0 , χ_1 and χ_2 are parameters.

The stochastic log labor productivity process $\Phi_z(\hat{z}_t)$ consists of two additive parts, a transitory component $\hat{z}_{1,it}$ and a more persistent component $\hat{z}_{2,it}$, where i indexes the (worker) household. Therefore, log productivity is

$$\hat{z}_{it} = \hat{z}_{1,it} + \hat{z}_{2,it}.$$

Each of the two components follows a jump-drift process, with jumps arriving at rate $\lambda_{z,j}$. At all times, the process drifts toward its mean of zero at rate $\beta_{z,j}$. Whenever there is a jump, a new log productivity state is drawn from a normal distribution, with $\hat{z}'_{j,it} \sim N(0, \sigma_{z,j}^2)$. Hence we have

$$d\hat{z}_{j,it} = -\beta_{z,j} \hat{z}_{j,it} + dJ_{j,it},$$

where $dJ_{j,it}$ captures the jumps in the process. The chosen parameters for this process are shown in Table 7 in the appendix.

Kaplan, Moll, et al. (2018) use this income process to ensure that the variance and the kurtosis of income changes in the model match those estimated from social security data.²² I

²²The implied unconditional variance of \hat{z}_2 is 0.18. In comparison to Kaplan, Moll, et al. (2018), my model features two additional, rather persistent, components to earnings: skill type s and human capital h . In my calibration, the variance of $\log(h)$ in the population is relatively small (0.01), and I shrink the discretized

assume that income risk follows the same process $\Phi_z(\hat{z}_t)$, regardless of a household's current occupation. This is in line with Kikuchi and Kitao (2020) who do not find significant differences between income processes estimated separately for the three occupational groups using PSID data.

The tax rate on labor income τ is set to 30%, and the lump-sum transfer from the government T amounts to 6% of total output Y_t .²³ The ratio of government bond supply to output in the initial steady state is chosen such that it implies a liquid interest rate r_b of 2% annually. Furthermore, I assume that government bond supply B_t is infinitely elastic, which implies a constant r_b over time. I make this assumption because letting the liquid rate respond endogenously would imply that it increases over time, which is in stark contrast to what has been observed in the data in recent decades. While there exists empirical evidence that the marginal product of capital has in fact risen since the 1980s, the riskless rate on Treasury bonds has been, if anything, on a downward trend (Moll et al., 2021). I discuss this issue again below.

The share of Non-ICT capital α is set to 0.34 and the depreciation rates of capital to $\delta_{ict} = 0.175$ and $\delta_s = 0.073$ annually, which are average values reported in Eden and Gaggl (2018). For the parameters of the occupational production function I resort to the baseline values used by vom Lehn (2020). Normalizing $a_m = 0$, he estimates $a_r = 0.18$ and $a_a = 0.77$ using data on occupational choices and worker skills, as proxied by wages, from the CPS. Like him, I assume that skills are standard normally distributed in the population, i.e. $s \sim N(0, 1)$.

Occupation-specific human capital Baseline estimates in Kambourov and Manovskii (2009b), who estimate returns to occupational tenure using data from the PSID, indicate that five (eight) years of occupational tenure are associated with an average increase in earnings of 12.0% (16.8%). In a related study, Sullivan (2010) confirms that occupation-specific capital is an important component of earnings using data from the National Longitudinal Survey of Youth. He finds returns to five years of occupational experience of 6.6% to 13.3%, depending on the specification. Furthermore, while he shows that the return varies widely across occupations, he estimates that five-year returns are 5.5% for clerical and 13.7% for craftsmen occupations, two groups of occupations with a high routine-task intensity (Autor

grid for \hat{z}_2 by the appropriate amount. Reducing the grid by $var(\log(w_{j^*}) + a_{j^*}s) = 0.11$, however, would drastically diminish the ability of the process to capture the moments targeted by Kaplan, Moll, et al. (2018). I therefore choose not to adjust the income process for the existence of the fixed skill type. This ensures that the moments they target pertaining to the risk properties of the process, i.e. the kurtosis and the variance of income changes, are left intact, while I obtain a somewhat higher variance in unconditional annual log earnings.

²³This tax and transfer system, taken from Kaplan, Moll, et al. (2018), behaves similarly as that in Heathcote et al. (2017), at least for annual incomes up to 100,000\$, as Figure 29 in the appendix shows. While it lacks tax progressivity, it allows me to conveniently isolate the impact of altering lump-sum transfers below.

Table 1: Calibrated human capital process

dt	1 year	2 years	5 years	10 years
Probability of becoming experienced	9.5%	18.1%	39.2%	63.1%
Expected wage growth for inexp. types	2.9%	5.5%	12.0%	19.3%

Notes: The first row shows the probability of having transited from \underline{h} to \bar{h} after dt years, i.e. $1 - e^{-\lambda_h \cdot 4 dt}$. The second row shows expected wage growth for inexperienced workers (\underline{h}), i.e. $(1 - e^{-\lambda_h \cdot 4 dt}) \cdot (\bar{h}/\underline{h} - 1)$.

and Dorn, 2013).

I use the two estimates from Kambourov and Manovskii (2009b) to calibrate the transition intensity from the inexperienced to the experienced state $\lambda_h = 0.025$, as well as the spread between high and low human capital $\bar{h}/\underline{h} = 1.31$. This implies that inexperienced workers become experienced on average after $1/(4 \cdot 0.025) = 10$ years. This number masks, however, that a substantial fraction of workers becomes experienced after only very few years, as the first row of Table 1 reveals. The calibrated values also imply that 18.2% of households are inexperienced in the stationary distribution of the steady state.²⁴

Lastly, note that several types of costs potentially affecting workers who switch their occupation are not captured here and could further discourage households from switching, especially when they are hand-to-mouth. In particular, households might not only switch the broad occupation, but at the same time also the industry or the firm, which would entail losses of industry- or firm-specific human capital (or a fall down a wage ladder within a firm). There could also be additional fixed pecuniary costs associated with switching the occupation, such as having to move to a new workplace, or having to buy a license and work clothes for the new occupation.

The relative price of ICT capital I take the estimates of the relative price of ICT capital $\frac{1}{q_{ict}}$ from Eden and Gaggl (2018). It is normalized to one in 1980 and then falls by almost 80% until 2013. Note that during the last years covered by Eden and Gaggl (2018), the fall of $\frac{1}{q_{ict}}$ visibly slows down. I assume that the fall continues at this reduced rate of 1% annually between 2014 and 2025 and then stays at its value of 0.225 forever. This is depicted in Figure 7.

I assume that agents in the model have perfect foresight over the path of q_{ict} . This is a strong assumption, given that there might have existed considerable uncertainty in the

²⁴One way to assess whether this discretization of the stochastic human capital process yields a realistic approximation is to ask how reluctant households are on average to switch occupations during the labor market transition in comparison to the data. If the model features a too large fraction of households who are experienced, the labor market transition will be too much driven by new labor market entrants. Section 5 presents evidence that the model features a balance between new labor market entrants and already experienced workers driving the transition that is approximately in line with the data.

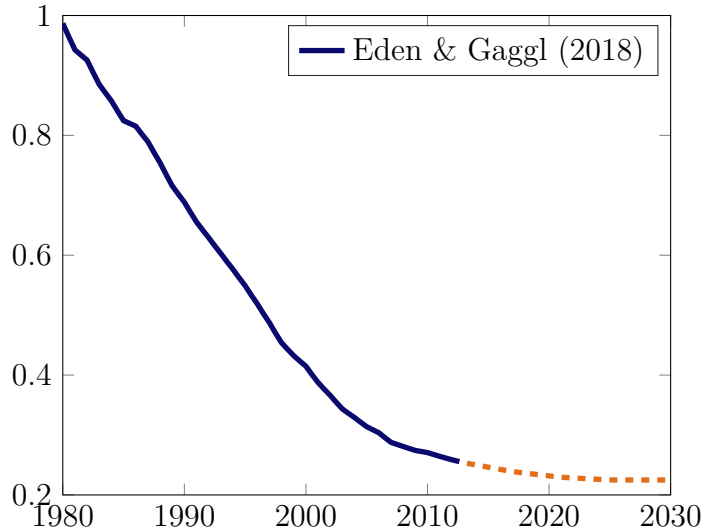


Figure 7: Relative price of ICT capital ($\frac{1}{q_{ict}}$).

1980s as to how the advancement of ICT capitals and machines in general would be able to substitute for routine labor. In line with evidence presented in Eden and Gaggl (2018), I also assume that the relative price of non-ICT capital q_s has stayed at a value of one at all times. Table 2 lists all externally calibrated parameters

4.5.2 Internal calibration

I calibrate the parameters of the production function (1) as is common in the literature (Jaimovich, Saporta-Eksten, et al., 2020; vom Lehn, 2020). In particular, I use the shares of hours worked in the three occupational groups, as well as the share of income accruing to labor, both in the old steady state and in the new one, to pin down the six share and elasticity parameters. For the 1980 hours shares targets I use the values reported in Autor and Dorn (2013), for the labor share I take the value from Eden and Gaggl (2018).²⁵

One complication that arises is that the precise values for the hours and labor income shares that the US economy will settle to in the hypothetical new steady state (i.e. after the labor market polarization has ended) are unknown. Neither can I use the model-implied shares for 2020 during the transition for the calibration to compare them to the observed numbers, as the computation of the transition between steady states takes a relatively long time to compute.

I therefore set the hours and labor income shares observed in 2020 as targets for the new steady state, implicitly assuming that they do not change much more in the future.²⁶ For

²⁵As noted above, and in accordance with Eden and Gaggl (2018), I assume that the income share accruing to non-ICT capital has been constant over time at $\alpha = 0.34$.

²⁶As can be seen in Figure 1, this seems like a reasonable assumption for the trend in hours shares. Also, Eden and Gaggl (2018) show that between 2010 and 2013 the labor share of income was approximately constant.

Table 2: Externally calibrated values

Parameter	Value	Description	Source or Target
ζ	$1/(45 \cdot 4)$	death rate	avg. lifetime 45 years
φ	2.24	labor disutil.	avg. labor time 8h/day
γ	1	elast. labor supply	Frisch elasticity of 1
\underline{b}	16,500\$	avg. qrtly. lab. income	Kaplan, Moll, et al. (2018)
r_b	2% (ann.)	liquid interest rate	Kaplan, Moll, et al. (2018)
τ	0.3	labor tax	Kaplan, Moll, et al. (2018)
T	$6\% \cdot Y_t$	lump-sum transfer	Kaplan, Moll, et al. (2018)
α	0.34	struct. capital share	Eden and Gaggl (2018)
δ_{ict}	0.175 (ann.)	deprec. ICT capital	Eden and Gaggl (2018)
δ_s	0.073 (ann.)	deprec. struct. capital	Eden and Gaggl (2018)
$[a_m, a_r, a_a]$	$[0, 0.18, 0.77]$	occ. prod. functions	vom Lehn (2020)
λ_h	0.025	trans. intensity	Kambourov and Manovskii (2009b)
\bar{h}/\underline{h}	1.31	earn. spread	Kambourov and Manovskii (2009b)

the hours shares I use the values from the 2019 wave of the SCF, depicted in Figure 1.²⁷ For the labor share, I use the value of 0.57 from Eden and Gaggl (2018). This procedure implies that, while I hit the three targets exactly in the new steady state, the model-implied changes in hours and labor income shares between 1980 and 2020 are somewhat smaller than in the data (as the economy is still transitioning to its new steady state). As Table 3 reveals, though, these deviations are relatively small.

The calibrated values of the production function are as expected. In particular, while routine labor and ICT capital are relatively easily substitutable ($\gamma_r > 1$), abstract labor is relatively complementary to the input provided by both routine labor and ICT capital ($\gamma_a < 1$). The substitution elasticity of manual labor with the nest composed of abstract labor and the routine input is again relatively high ($\gamma_m > 1$).²⁸ Given the specified production function as well as these calibrated parameters, it can be shown analytically how wages in each occupation respond in the short term (i.e. when factor inputs are held fixed) upon a rise in q_{ict} . Appendix C.3 discusses this further and shows that while manual and abstract wages rise on impact when ICT capital becomes cheaper, routine wages fall.

Concerning the demand side of the economy, I need to calibrate five more parameters that are also present in Kaplan, Moll, et al. (2018). I use the same targets as they do to pin them down. In particular, I calibrate the effective discount factor $\hat{\rho} = \rho + \zeta$, the borrowing

²⁷The numbers from CPS data shown in Kikuchi and Kitao (2020) are very similar.

²⁸The calibrated values of these parameters are similar to those used in the previous literature. For instance, Jaimovich, Saporta-Eksten, et al. (2020) calibrate $\gamma_m = 1$, $\gamma_r = 1.85$ and $\gamma_a = 0.48$. vom Lehn (2020) uses equipment instead of ICT capital in the production nest with routine labor, rendering his production function parameters less comparable to the ones I use here.

Table 3: Internally calibrated values

Parameter	Value	Description	Target (Model)
μ_m	0.13	PF share man. 1980 Hrs share rout.:	58.5% (58.3%)
μ_r	0.94	PF share rout. 1980 Hrs share abstr.:	31.6% (31.3%)
μ_a	0.67	PF share abstr. 1980 Labor share:	64.0% (64.0%)
γ_m	1.59	PF elast. man. 2020 Hrs share rout.:	44.2% (46.2%)
γ_r	2.38	PF elast. rout. 2020 Hrs share abstr.:	42.9% (41.2%)
γ_a	0.25	PF elast. abstr. 2020 Labor share:	57% (57.8%)
$\hat{\rho}$	0.017	disc. rate	\tilde{K}/Y : 2.92 (2.79)
κ	0.018	borr. wedge	B/Y : 0.26 (0.26)
χ_0	0.12	adj. costs	share poor HtM: 0.10 (0.10)
χ_1	0.93	-	share wealthy HtM: 0.20 (0.17)
χ_2	1.56	-	share neg. liq. b : 0.15 (0.15)

wedge κ and the parameters of the portfolio adjustment cost function $\chi(\cdot)$ using both the ratio of liquid and illiquid assets to output in the economy, the shares of poor and wealthy hand-to-mouth households, and the share of households with negative liquid assets.²⁹ I find very similar values for these five parameters as Kaplan, Moll, et al. (2018), and hit the targets relatively well, as can be seen in Table 3.

4.6 Untargeted moments

Relative wages and interest rate While I targeted the changes in hours worked directly in the calibration, the evolution of relative wages between occupational groups were left untargeted. Figure 8 reports the model-implied evolution of routine wages to abstract as well as manual wages during the transition. While the routine to manual wage falls by about 4.8% at its trough, the fall of the routine relative to the abstract wage is much more pronounced (25.0% at its trough in the mid 2020s).

This qualitative pattern is in line with the empirical evidence provided by Cortes (2016). Be reminded that Figure 8 plots (relative) occupational wage premia, not average wages in occupations. These wage premia are not easily measured in the data, since to obtain knowledge of them one would need to observe the same workers in all three occupations. These wage premia have fallen by 18.9%, and those of routine to abstract workers by 44.3%.³⁰ Automation therefore explains about 25% of the drop in routine relative to manual, and 56% of the drop in routine relative to abstract wages in my model. The magnitude of these numbers is comparable to the findings in Jaimovich, Saporta-Eksten, et al. (2020) and Moll et al. (2021).

²⁹I target these statistics in the initial steady state.

³⁰Figure 30 in the appendix reports his estimated coefficients.

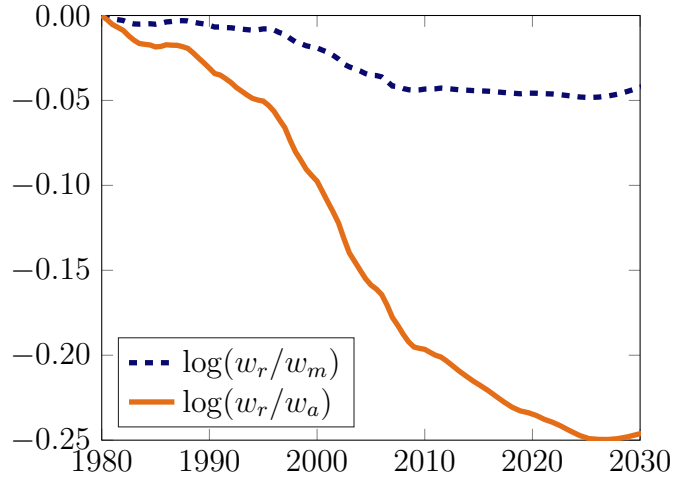


Figure 8: Model-implied change in relative wage premia compared to 1980.

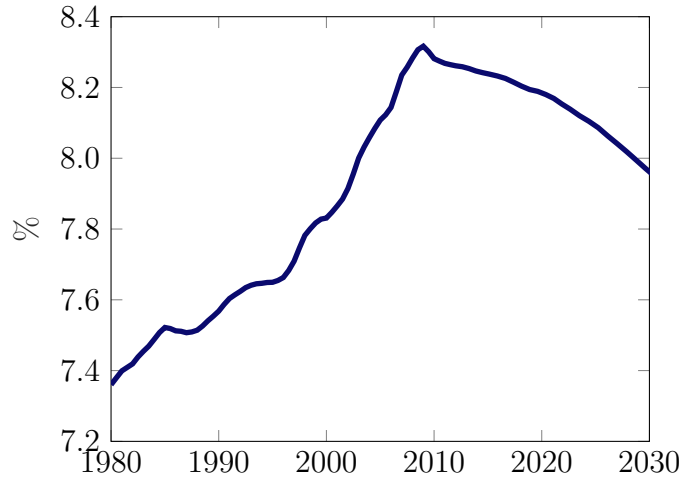


Figure 9: Model-implied (annual) interest rate r_k (in %).

Figure 9 plots the evolution of the interest rate. Since firms demand more capital when its relative price is low, the interest rate is higher in the final than in the initial steady state. This is borne out by a prolonged rise in r_k during the transition period, with some degree of overshooting, until it settles at its new level of 7.65%. While the data unambiguously show that risk-free interest rates have been on a secular decline over the recent decades, Moll et al. (2021) discuss empirical evidence showing that the marginal product of capital, measured by the return to U.S. business capital, has indeed been rising.³¹

Wage changes upon occupational switch Cortes (2016) also estimates expected wage changes over several horizons for those routine workers who switch to the manual or to the abstract occupations. He finds that expected wages one year after the switch are by 11.2% lower for routine workers switching to manual occupations compared to those who

³¹The reader be reminded here that I have assumed government bond supply to be infinitely elastic. Hence r_b is constant at its level of 2% at all time. The excess return on capital over riskless bonds therefore also rises in my model, as in Moll et al. (2021).

stay. Only over longer horizons (ten years) he finds that expected wages are higher for those who make the switch. This pattern is different for routine workers switching to the abstract occupations, for whom he estimates that expected wages are higher for switchers both over the short run (the expected increase one year ahead is 3.4%) and the long run (16.3% ten years ahead) than for stayers.

These numbers are difficult to account for by the model. During the transition, the expected wage change one year ahead for routine workers switching to manual occupations, compared to those who stay, is 0.0%, higher than what Cortes (2016) finds. In contrast, compared to stayers the expected wage change in the model is -8.8% for routine workers switching to the abstract occupations, lower than in Cortes (2016).³²

One explanation for this is that the switching patterns observed in the data contain some amount of career progression. Concretely, the positive expected wage changes for switchers from routine to abstract are likely driven by a subset of workers who move up the career ladder (moving up to management positions), while a switch from routine to manual is less likely to reflect such career progression. The model of Section 4 does not capture such career aspects, as skill type s perfectly predicts occupational group, at least in steady state. Rather, what the analysis attempts to capture are occupational switches induced by technological change which exceed the usual career movements that would take place in any case (see the discussion on occupational mobility above).

One way to get at this in the data, is to study routine workers whose wages actually fell when they switched to the abstract occupations. This makes an occupational move reflecting career progression less likely. In 31% of the cases in which a worker moved from routine to abstract occupations, workers' hourly wages two years after the switch were lower than before the switch.³³ For this subset of switches, the average wage loss was 19%, the median loss 9%, and hence much closer aligned with the model prediction of 8.8%.

Another way to identify actual career changes, entailing a loss of human capital, and not mere career progression, is by considering data from the US Department of Labor's Trade Adjustment Assistance (TAA) program. This program is designed to assist workers who are adversely affected by foreign trade in finding a new career. I relegate a further discussion of the program to Section 6, which discusses policy, and to Appendix E. Note here, though, that according to the TAA's website, earnings upon re-employment after participating in

³²Figure 31 in the appendix depicts the full set of estimates, both from the model and from Cortes (2016). Average wage losses for leavers to the manual occupations are so small in absolute terms in the model because during the transition few experienced routine workers switch to the manual occupations. The rise in the manual employment share is largely due to inexperienced households switching and new-born households choosing the manual occupations. This is different for the abstract occupations, into which a considerable amount of experienced workers switch during the transition. The main reason for this is that the rise in the manual relative to the routine wage is much less pronounced than that of the abstract to routine wage (Figure 8), which makes losing occupational human capital to join the manual occupations relatively unattractive.

³³These numbers are based on own calculations using the publicly available replication material from Cortes (2016). He uses data from the PSID, years 1968 to 2007.

	SCF (1989)			Model (1980)		
	HtM	wealthy HtM	poor HtM	HtM	wealthy HtM	poor HtM
Manual	42%	20%	22%	29%	19%	11%
Routine	32%	20%	13%	28%	18%	10%
Abstract	16%	13%	3%	23%	15%	8%

Table 4: Hand-to-mouth shares by occupation.

Notes: Wealthy HtM are hand-to-mouth households with positive illiquid assets, poor HtM are those with zero illiquid assets.

the program were on average 15% below those before participation.³⁴

Hand-to-mouth shares While the calibration directly targeted unconditional shares of hand-to-mouth households in the economy, it left the shares conditional on broad occupational group untargeted. These moments are reported in Table 4 for the initial steady state of the model as well as for the earliest available wave of the SCF (1989). Comparing first the values for overall hand-to-mouth shares it becomes apparent that the model indeed reproduces the ordering along broad occupational groups. It does, however, understate somewhat the variance that exists in the data. While 42% of manual and 16% of abstract workers are hand-to-mouth in the data, the corresponding numbers are 30% and 23% in the model.

A further decomposition into wealthy and poor hand-to-mouth households makes clear that the absence of larger variance between shares in the model is due to the existence of too few poor hand-to-mouth households in the manual and too many of them in the abstract occupations. The model-implied shares of wealthy hand-to-mouth households are in fact very closely aligned with those in the data.

5 Transition

This section studies the transition between the steady state with a high relative price of ICT capital and a new steady state with a relative price of ICT capital that is almost 80% lower. The focus lies on demonstrating that the interaction of occupation-specific human capital and the existence of a large share of hand-to-mouth households causes a lag in the labor market transition between the two steady states.

³⁴See Table 8 in the appendix. Observe, however, that job changes of participants in the TAA program usually entail a switch in the industry, not (only) in occupation. This leads to an (additional) loss in industry-specific human capital, as compared to a pure occupation-specific human capital loss in my model.

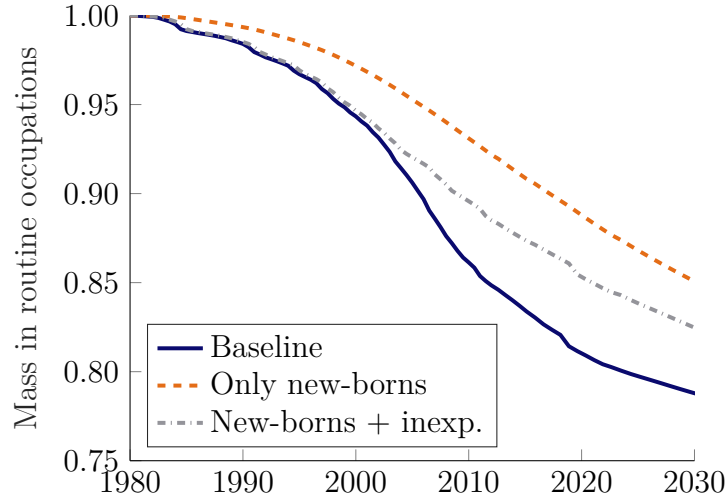


Figure 10: Mass of households employed in routine occupations (1980=1).

Notes: Blue solid: solution of the baseline model. Orange dashed: counterfactual with initial occupational choices made permanent for rest of life. Grey dashed: counterfactual with occupational choices made permanent once households become experienced.

5.1 The decline of aggregate routine labor

The solid blue line in Figure 10 plots the mass of households employed in the routine occupations in the model economy, with 1980 normalized to a value of one. While the magnitude of the eventual decline was targeted in the calibration, the dynamics of the fall of routine labor, in particular the pronounced speeding up of it in the early 2000s, is also in line with the data (Cortes, Jaimovich, and Siu, 2017).

Cortes, Jaimovich, Nekarda, et al. (2020) provide empirical evidence highlighting that 34 to 43% of the fall in routine hours is due to a reduced propensity to enter these occupations from non-employment and unemployment. They further show that the declining propensities of young workers (16-34 years) have been especially important in accounting for the drop in aggregate routine labor. While I do not model unemployment, one can interpret the entry of new-born households as entry from non-employment. I therefore conduct a counterfactual exercise to assess whether my model performs realistically in this regard.

Starting in the initial steady state, I use the optimal occupational policy functions j_t^* of workers to decide which occupation new labor market entrants choose at the beginning of their work life. Afterwards, however, I counterfactually assume that they never switch the occupation, i.e. I iterate forward the distribution of households over the state space assuming that households only make an occupational choice at the beginning of their lives. This is therefore an out-of-equilibrium exercise that abstracts from general equilibrium effects on initial occupational choices and on wages, just as in Cortes, Jaimovich, Nekarda, et al. (2020). Details on how I construct this and all following counterfactuals are relegated to Appendix C.4.

The orange dashed line in Figure 10 depicts the resulting mass of routine workers in

the economy. It falls much more slowly than the actual mass, which implies that some of the fall in routine work in the model is due to voluntary switching of households. In 2020, $\frac{1-0.89}{1-0.81} = 59\%$ of the fall in routine labor is accounted for in the model by the reduced propensities of new labor market participants to enter the routine occupations, somewhat higher but in a similar range as the value found in Cortes, Jaimovich, Nekarda, et al. (2020).

Further decomposing the fall in routine hours, the grey dashed line in Figure 10 depicts a second counterfactual. Here, I use the optimal occupational choices not only of the new labor market entrants to iterate forward the distribution of households over the state space, but also for all inexperienced households (i.e. those with $h = \underline{h}$). Only once households become experienced in their occupation ($h = \bar{h}$) I counterfactually assume that they never change their occupation again. Two results stand out.

First, in the first two decades the grey dashed line tracks the blue solid line very closely, implying that almost all occupational switching during this time was done by inexperienced households with little attachment to the routine occupations. Second, after 2000 the two lines separate visibly, indicating that in the later decades some of the fall in routine labor in the economy was achieved by experienced households switching. This ordering of events does not surprise, given that relative wages in the manual and abstract occupations must rise much more relative to the routine wages in order for experienced workers to make a switch (cf. Section 3). The fact that experienced routine workers begin to switch starting in the early 2000s can also be related to the dynamics of the relative routine wage, whose fall significantly sped up around this time (see Figure 8).

5.2 The impact of hand-to-mouth households

The simple model of Section 3 demonstrated that in a dynamic setting, in which households are exposed to changing relative wages between occupations, occupational choices can depend on how easily these households are able to borrow against future income. In the full model presented here, the key friction is that labor income risk is uninsurable. In combination with this friction there exist several reasons why households have difficulties to borrow against future income at all times.

First, there is an ad-hoc borrowing constraint \underline{b} that prevents households from taking on more debt once they have reached it. Second, the borrowing wedge κ makes it more costly to take on debt $b < 0$ than it is to be a lender $b > 0$. As Section 3 showed, a larger interest rate makes switching to the occupations that are more unattractive today but promise higher wages in the future less likely. Furthermore, even households who own considerable illiquid assets might not be able to access these assets quickly. In particular, the portfolio adjustment costs $\chi(\cdot)$ can prevent them from tapping their reserves fast enough to cushion their consumption against fluctuations in wages. For all of these reasons there exists a considerable fraction of households in the economy who might choose to work in the routine occupations for a longer time than households who have saved up comfortable

buffers of liquid assets that insure them against idiosyncratic shocks to their income.

5.2.1 Individual decision rules

To exemplify this point, I now analyse the occupational choices of a particular subset of workers especially exposed to the technological change of the recent decades. In particular, I study when experienced routine workers, who were most exposed to the technological change, decide to exit the routine for the abstract occupations. To this end, I consider the occupational policy functions j^* of the subset of workers who are experienced (\bar{h}) in the routine occupation and are of skill type $s = \bar{s}_{\text{old}}$. Workers of this skill type optimally work in the routine occupations before, and in the abstract occupations after polarization has shifted relative wages in favor of performing abstract work (cf. Figure 6). However, making this switch entails a loss of human capital \bar{h} for experienced routine workers, and is therefore relatively unattractive during the early years of the transition.

Figure 11 visualizes this choice over time, once for the households that are hand-to-mouth, and once for those that are not. It plots the probability x_t of leaving the routine (and entering the abstract) occupations, averaged over the dimensions of wealth (b and \tilde{k}) and productivity (z) using the stationary distribution of households in the initial steady state $\Gamma(i)$, i.e.

$$x_t = \frac{\int_{i:\{s=\bar{s}_{\text{old}}\wedge j_{1980}^*=r\wedge h=\bar{h}\}} \mathbf{1}_{\{j_t^*=a\}} d\Gamma(i)}{\int_{i:\{s=\bar{s}_{\text{old}}\wedge j_{1980}^*=r\wedge h=\bar{h}\}} d\Gamma(i)}, \quad (5)$$

where $\mathbf{1}_{\{\cdot\}}$ denotes the indicator function.³⁵ While for drawing the orange dashed line in Figure 11, corresponding to choices made only by hand-to-mouth households, I replace $\Gamma(i)$ in (5) with

$$\Gamma(i) \cdot \mathbf{1}_{i:\{b=0\vee b=-\underline{b}\}},$$

I replace it with

$$\Gamma(i) \cdot \mathbf{1}_{i:\{b\neq 0\wedge b\neq -\underline{b}\}}$$

for drawing the blue solid line, i.e. the scenario in which I average only over occupational choices of non-hand-to-mouth households. A value of $x_t = 0$ therefore indicates that the mass of experienced workers of skill type s_{old} who would leave the routine for the abstract occupations at time t equals zero, while $x_t = 1$ implies that all of these workers would make the switch if they found themselves working in the routine occupation at time t .

Figure 11 can be interpreted in the following way. While before 1994 close to none of the experienced routine workers with $s = \bar{s}_{\text{old}}$ find it optimal to switch to the abstract occupations, after 1994 an increasing share of households does. However, it is those households that

³⁵Using the current distribution of households over the state space at each point in time $\Gamma_t(i)$ in the computation of x_t leads to very similar results. However, as experienced routine workers of this skill type keep leaving the occupation (or die), the mass of this type of workers approaches zero over time. Computing x_t over an increasingly small set of workers leads to large jumps in x_t during the later years of the transition. Therefore, I display the exit probabilities that use the (constant) steady state distribution at all times here.

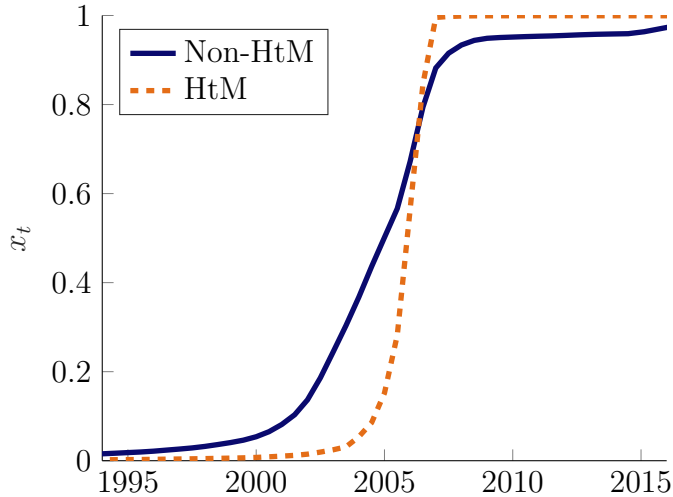


Figure 11: Exit decision x_t of experienced routine workers with $s = \bar{s}_{\text{old}}$, averaged across wealth and productivity.

are not hand-to-mouth who move first. For hand-to-mouth households to make a switch, the wage premium w_a has to increase further relative to w_r in order for them to find it optimal to switch. This is again a manifestation of how the occupational choices of workers are significantly distorted when they are hand-to-mouth, just like it was the case in the simplified model of Section 3. Figure 33 in the appendix further documents that the same pattern holds when studying the average probability of inexperienced workers with $s = \bar{s}_{\text{new}}$ to enter the abstract occupations.

One more, so far not discussed effect becomes apparent in Figure 11. While hand-to-mouth households are initially more reluctant to switch than non-hand-to-mouth households, at some point their willingness to do so overshoots that of the better insured agents. The reason for this is the multiplicative structure with which human capital enters labor income in the model. This multiplicative structure implies that the opportunity cost of switching the occupation is low whenever the idiosyncratic productivity component z assumes a small value. Since hand-to-mouth households are systematically more likely to exhibit currently low levels of z , this effect in isolation makes them somewhat more willing to change the occupation than non-hand-to-mouth households, who typically feature high values of z .³⁶ As Figure 11 suggests, however, this effect is quantitatively outweighed by the smaller tolerance of hand-to-mouth households towards the drop in earnings caused by switching occupations. This will become even more evident once I aggregate up all decision rules in order to assess the impact of hand-to-mouth households on the evolution of aggregate routine hours, which I turn to next.

³⁶This effect would vanish if human capital entered into the specification of labor income additively. The effect would also become less important if being hand-to-mouth was caused predominantly by preference heterogeneity (Aguiar et al., 2020; Gelman, 2021), rather than by having received a low idiosyncratic productivity draw, as it is in my model.

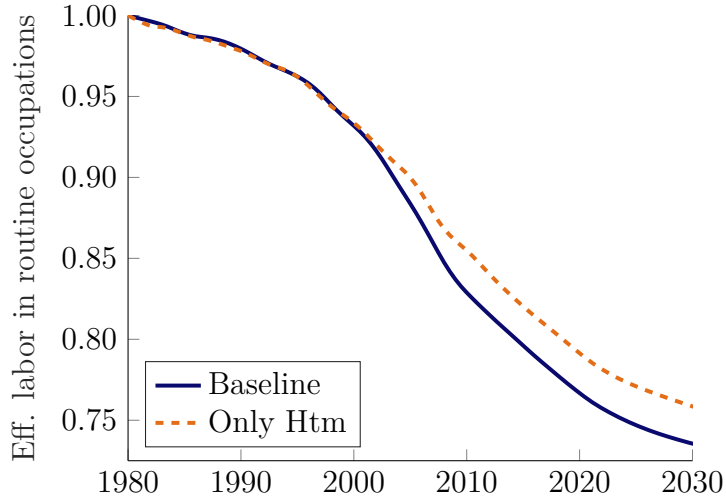


Figure 12: Effective labor in routine occupations (1980=1).

Notes: The orange dashed line uses average policy functions of hand-to-mouth households for occupational choices of all households along the transition.

5.2.2 Aggregate implications

I now aggregate up all individual occupational choices to assess whether the large share of hand-to-mouth households in the US economy has affected the dynamics of the overall routine hours share. I do this by simulating a counterfactual transition in which I always apply the average occupational choices x_t of those households who are currently hand-to-mouth to all households in the economy. Specifically, at any point in time t during the transition period, I consider the households with liquid assets $b = 0$ or $b = -\underline{b}$, and use their occupational choices, averaged across the dimensions of wealth (b and \tilde{k}) and productivity (z), for all households in the economy. I then compare the resulting amount of effective labor employed in the routine occupations to that of the baseline transition. Appendix C.4 explains the details.

Figure 12 shows the results. While during the first years of the transition there are no visible differences between the two curves, starting in the early 2000s the two lines separate. This is due precisely to the mechanism discussed in the simplified model of Section 3. The interaction of occupation-specific human capital and market incompleteness leads to a delayed labor market transition, as occupational choices become sticky. The horizontal distance between the blue solid and the orange dashed line in Figure 12, a measure of how much the presence of hand-to-mouth households slows down the labor market transition, amounts to about three years on average during the period between 2000 and 2020.

As discussed above, the adjustment of labor away from the routine occupations can be accomplished via two margins: new-borns can choose to no longer enter the routine occupations, and experienced routine workers might leave them. Figure 10 clarified that both of these margins are important during the transition to a new steady state. As the simple model in Section 3 demonstrated, theoretically, the fact that some households are

hand-to-mouth affects both of these margins.

Quantitatively, however, it turns out that in the calibrated model only the second margin of labor market adjustment is distorted in a way that meaningfully affects aggregates. To see this, I conduct another counterfactual, which uses the average occupational choices of hand-to-mouth households for the inexperienced, and those of all households for the experienced. This simulation leads to an almost identical evolution of effective labor in the routine occupations as in the baseline transition.³⁷ It is therefore the fact that experienced routine workers who are hand-to-mouth are reluctant to switch the occupation which drives the difference between the two lines in Figure 12. Note, however, that this stark result is driven by the simplifying assumption of only two human capital types (experienced vs. inexperienced), with intermediate types being absent. A distinction into more than two human capital types would naturally weaken this strong result.

5.2.3 Raising the transfers

To further demonstrate the mechanism at work, I ask the following question: How would occupational choices have changed if households had received higher government transfers T_t throughout the transition period? Intuitively, higher non-labor income, paid out unconditionally, should better enable workers to make the occupational choices that maximise their lifetime income and bear the cost of temporarily lower earnings in the manual and abstract occupations. To address this, I conduct the following, out-of-equilibrium, experiment. Throughout the transition period, I raise the lump-sum transfer T_t from the government to three times its original level, keeping everything else equal. In particular, all factor prices as well as the labor tax τ are kept at the same levels as during the baseline transition. I then re-calculate the average exit decisions of experienced routine households as described above.

Figure 13 plots x_t for workers of skill type \bar{s}_{old} once using the decision rules from the baseline transition (the same as in Figure 11) and once when the transfers are higher. A clear leftward shift of the exit decisions becomes visible, implying that households leave the routine occupations earlier when the higher transfers are in place than in the baseline. The shift is most pronounced for the households that are hand-to-mouth, but is also visible for those that are not. As discussed earlier, in a full-fledged incomplete markets model as the one proposed here, even households who do not hold exactly zero liquid assets or are up against the borrowing constraint currently, realise that they might be hand-to-mouth in the near future. Therefore, higher transfers affect the behaviour even of these, relatively unconstrained agents.

Of course, having households leave the routine occupations in a less delayed fashion is likely not the primary goal of any policy maker. The more interesting question, which I will turn to next, is how different policies affect not only switching behaviour, but also aggregate output as well as social welfare. Furthermore, tripling the transfers to every household is

³⁷See also Figure 32 in the appendix.

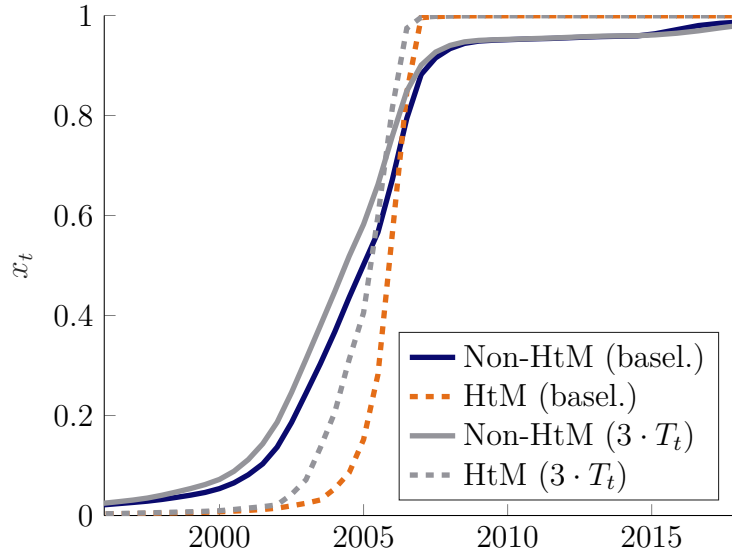


Figure 13: Exit decision x_t of experienced routine workers with $s = \bar{s}_{\text{old}}$, averaged across wealth and productivity.

Notes: The grey lines correspond to a counterfactual scenario in which I assume that transfers are at three times their baseline values during the transition period, holding everything else constant.

vastly expensive and not a very targeted policy to address the friction outlined so far.³⁸ In the next section I therefore discuss more targeted policies, which potentially lead to a smaller delay in the labor market transition as well as an increase in output and social welfare.

6 Policy

The fundamental cause of the protracted labor market transition highlighted so far is the incomplete markets friction. It causes households close to the borrowing constraint to work in the routine occupations for a longer time period than if they could insure against the idiosyncratic risk. The previous section also highlighted that it is almost entirely the distortion of the decisions taken by experienced routine workers that leads to a lag in the reshuffling of the workforce. To directly address this friction, I start by proposing a simple labor market policy, that offers transfers to experienced routine workers who leave their occupation for a new one. I then compare the results of this policy to the introduction of a re-training program, financed by the government, and a temporary tax on ICT capital.

6.1 Switching subsidy

In this section, I assume that the government pays an additional transfer to those experienced routine households who choose to leave their occupation and enter the abstract or manual occupations, topping up the lump-sum transfer T that every household in the economy

³⁸Raising T_t from its baseline value of 6% of average income to 18% would require an increase in labor taxes by approximately $12\% / (1 - \alpha) = 18$ percentage points, i.e. from a baseline value of $\tau = 30\%$ to 48%.

receives. This payment better insures the affected workers against future fluctuations in labor income, alleviating the distortions stemming from the incomplete markets friction. The proposed policy cushions the fall in earnings that is due to the loss in human capital from \bar{h} to \underline{h} , and thus makes the transition to a new broad occupational group for experienced routine workers smoother. It simultaneously subsidizes labor in those occupations for which demand in the economy is rising and incentivizes experienced routine workers to work in them.

To this end, I introduce a new idiosyncratic state variable $v \in \{0, 1\}$ that captures entitlement status to the higher transfer. It assumes a value of one once a household becomes an experienced routine worker ($j^* = r, h = \bar{h}$). This entitles her to pick up the additional transfer whenever she decides to quit the routine occupations and work in the manual or abstract occupations (with the ensuing depreciation of human capital to $h = \underline{h}$). I assume that households stay entitled until they become experienced in the manual or abstract occupations, at which point the entitlement to the additional transfer expires and v is set to zero.³⁹ I allow workers who pick up the subsidy to return to the routine occupations at any point in time. Because I assume no recall of past human capital, however, they do this with low human capital \underline{h} (cf. Section 4). Furthermore, they only receive the additional transfer while working in the manual or the abstract occupations.

In practice, where h is unobserved, entitlement could be conditioned on having worked in the routine occupations for longer than $1/(4 \cdot \lambda_h) \approx 10$ years. Similarly, the government could let the benefits run out either whenever wages of the worker have grown by $\bar{h}/\underline{h} - 1 \approx 31\%$ or alternatively after ten years have passed since the switch occurred. To rule out that transfers are picked up by workers who switch from routine to abstract occupations as a matter of career progression, which I have abstracted from in the model, in practice the transfer could also be limited to those experienced routine workers who exhibit wage losses, or even wage losses exceeding a certain threshold, upon switching.⁴⁰

I assume that the increase in the transfer amounts to a factor ψ of the average net earnings loss that experienced routine workers face when they leave their occupation. Concretely, the transfer is increased by ψ times

$$(\bar{h} - \underline{h}) \cdot (1 - \tau) \cdot w_{r,1980} \cdot 0.5 \cdot \phi_r(\underline{s}_{\text{old}}) \approx 380\$ \text{ (monthly)}$$

³⁹I make this assumption for simplicity. It avoids having households of the type ($j \in \{m, a\}, h = \bar{h}, v = 1$), which reduces computational cost. In principle, one could also experiment, for instance, with higher benefits over shorter periods of entitlement.

⁴⁰The closest empirical analogue to the proposed transfer is the US Department of Labor (DoL)'s Reemployment Trade Adjustment Assistance (RTAA). It offers workers aged 50 and higher, who were negatively affected by foreign trade, a 50% wage supplement if their re-employment resulted in a lower wage. I provide details of the TAA program, and a number of case studies of workers who participated, in Appendix E. The main difference between the scheme proposed here and RTAA is that entitlement to the proposed transfer here is based on former employment in the routine occupations, not in a trade-affected industry (although those two overlap). The transfer I propose is also paid over a longer time period, on average ten years, than the average participation length in all TAA programs (510 days in 2019 according to the TAA's website).

for entitled workers working in the manual occupations, and by ψ times

$$(\bar{h} - \underline{h}) \cdot (1 - \tau) \cdot w_{r,1980} \cdot 0.5 \cdot \phi_r(\bar{s}_{\text{old}}) \approx 530\$ \text{ (monthly)}$$

for those working in the abstract occupations.⁴¹ The factor 0.5 indicates the average labor supply in the economy. I assume that eligible workers can start collecting this transfer at the beginning of the transition period in 1980. To be able to compute the transition to the final steady state, which does not feature the higher transfers, I assume that entitlement to the additional transfers expires in 2040.

The government finances the policy by increasing τ_t , i.e. through higher labor income taxation. I assume that government expenditures G_t as well as the standard transfers T_t (which every household receives) are kept at the levels they assume throughout the baseline transition without policy at any point in time. I use the following welfare criterion, which sums expected lifetime utilities across all households, to assess the policy:

$$W = \int_{T=0}^{\infty} \mathbb{E} \left[\int_{t=T}^{\infty} e^{-(\rho+\zeta)(t-T)} u(c_t, \ell_t) dt \right] dT .$$

Figure 14 depicts the absolute change in the welfare criterion for different replacement rates ψ compared to the baseline case in which $\psi = 0$.⁴² The welfare change is inversely u-shaped in ψ . It reaches its maximum roughly for a value of $\psi = 0.5$, i.e. replacing half of average lost earnings is optimal according to this criterion. This implies additional monthly transfers of 190\$ to manual and 260\$ to abstract workers who were formerly experienced routine workers. The increase in τ necessary to finance this policy is relatively small, and never exceeds 0.25 percentage points (see Figure 34 in the appendix).

For replacement rates higher than 0.5, the welfare improvement due to the policy decreases again, and for $\psi = 1$ overall welfare is even lower than in the baseline scenario with $\psi = 0$. This is because with rising ψ , distortionary taxes τ have to increase as well, putting a burden on all households and disincentivizing labor in general. Also, with ever higher transfers, more and more households switch out of the routine occupations, further increasing the share of households who are paid the transfer and thereby raising the cost to finance it.

It is possible that the proposed policy simply redistributes income, which can always have positive welfare effects in a model with heterogeneous agents and strictly concave utility functions. To shed light on this issue, I also conduct a placebo reform. In this case, I introduce the subsidy described above, but I compute a “transition” in which no technological

⁴¹All values are expressed in 2019 US dollars. I assume that the transfer does not grow over time in real terms.

⁴²As defined here, W does not assume a finite value. In practice, when calculating welfare differences between policies and the baseline, I use households’ utilities up until the year 2070 (an average lifetime after q_{ict} stops rising in 2025) in the calculation of W to ensure that it is finite. Since I phase out the additional transfers in 2040, the difference between welfare under the policy and the baseline transition approaches zero as t goes to infinity.

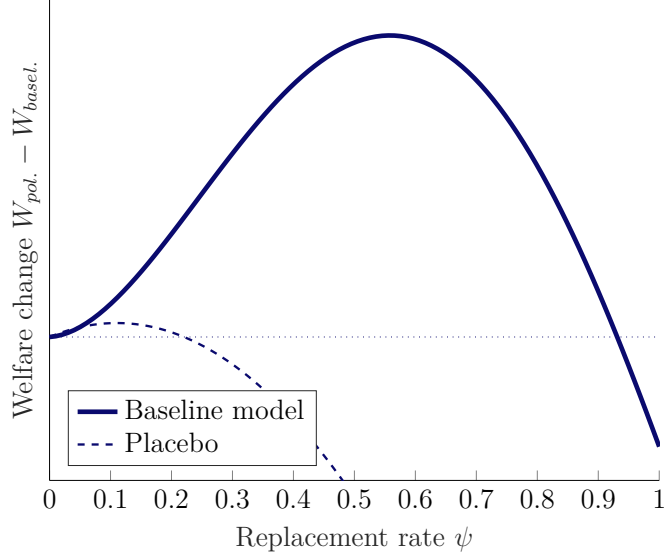


Figure 14: Welfare improvements of introducing switching subsidies with different replacement rates ψ .

Notes: “Placebo” corresponds to the case in which the same policy is implemented, but no technological change takes place (i.e. with constant q_{ict}).

change occurs, i.e. $q_{ict} = 1$ at all times.⁴³ This offers experienced routine workers the same potential insurance as in the case when technological change does occur, which they might want to pick up when they are hit by a bad realization of the productivity shock z . The distortion stemming from the interaction of market incompleteness and changing relative wages between occupations is no longer present in this placebo, however. As the dashed line in Figure 14 shows, there are indeed close to no welfare gains from introducing the higher transfers for experienced routine workers absent technological change. I return to a discussion of re-distribution versus production further below.

How large are the welfare gains from implementing a replacement rate of $\psi = 0.5$? To answer this question, I compare expected lifetime consumption of agents born at different periods in time, once under the baseline transition and once when the policy with $\psi = 0.5$ is active. In particular, for each skill type s , and for a cohort entering the labor market in $T = \tilde{T}$, I compute the value ϕ which equalizes the following two expressions

$$\mathbb{E} \left[\int_{t=\tilde{T}}^{\infty} e^{-(\rho+\zeta)(t-\tilde{T})} u(\phi c_t^{\text{basel.}}, \ell_t^{\text{basel.}}) dt \right] = \mathbb{E} \left[\int_{t=\tilde{T}}^{\infty} e^{-(\rho+\zeta)(t-\tilde{T})} u(c_t^{\text{pol.}}, \ell_t^{\text{pol.}}) dt \right].$$

This indicates by what fraction households could increase their lifetime consumption in the baseline scenario (in expectation and keeping labor supply fixed) at the date of entrance into the labor market if the policy were enacted. Figure 15 depicts the values of ϕ across skill type s , for cohorts who enter the labor market in 1990 and 2000, i.e. who are born approximately in 1970 and 1980, respectively.⁴⁴

⁴³This is similar to introducing the policy in the initial steady state and comparing welfare with the baseline steady state. However, as in the baseline case of the policy, I assume that all transfers expire in

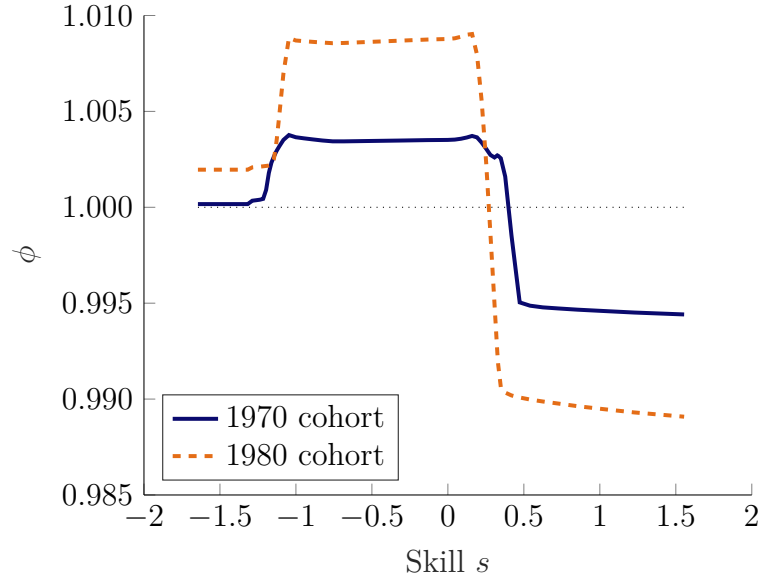


Figure 15: Increase in expected lifetime consumption due to switching subsidy with $\psi = 0.5$.

A clear segmentation into three groups is visible, corresponding to the three broad occupational groups that households initially work in. The clear winners from the policy are the medium-skilled types, who typically sort into the routine occupations. For those born in 1980, these skill types can increase lifetime consumption by around 0.9%. The clear losers of the reform are high-skilled workers, who suffer most from the increase in labor taxation.

Figure 16 depicts which skill types take up the additional transfers. Especially those routine workers with skill types close to the initial cut-offs $\underline{s}_{\text{old}} = -1.26$ and $\bar{s}_{\text{old}} = 0.54$ are prone to leaving their occupations for either the manual or the abstract occupations. The earnings of types in the center would fall by too much to make the switch optimal, which explains the u-shape in between the cut-offs (cf. Figure 5).

Why is it that even those routine workers who hardly ever pick up the additional benefits profit from the policy in terms of welfare? An answer to this can be found in Figure 17, which plots routine relative to abstract wages, both in the baseline transition and under the policy. Introducing the policy substantially dampens the fall in routine wages during the transition, making every routine worker better off, even if they never collect the benefits. At its trough, the fall in the relative routine to abstract wages is mitigated by more than 2 percentage points when introducing the policy.

Strikingly, as Figure 15 revealed, even the low-skill workers, who work in the manual occupations and never pick up the additional transfer, benefit from the reform, at least

2040 in the placebo reform, which would be impossible when implementing the reform in the steady state.

⁴⁴One way to calculate the aggregate welfare gain (across all skill types and cohorts) is to use the aggregate change in welfare, depicted in Figure 14. Using the absolute change in welfare for $\psi = 0.5$, households alive between 1980 and 2070 could have increased their consumption on average by 0.10% during that time period, had the policy been active. As Figure 15 shows, though, this masks substantial heterogeneity both across skill types and across cohorts.

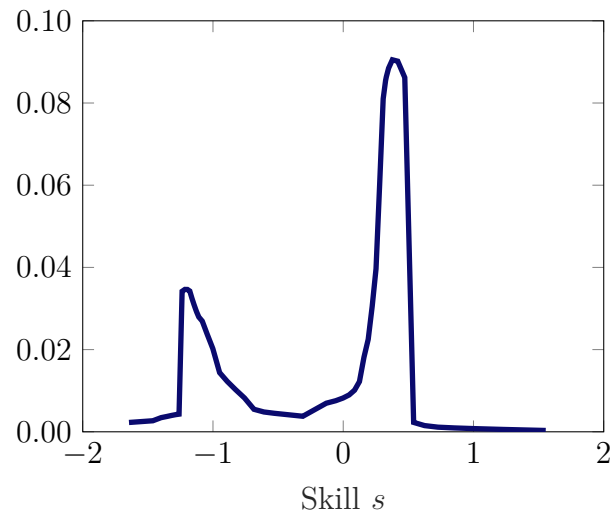


Figure 16: Share of households who collect the subsidy, averaged over 1980-2040.

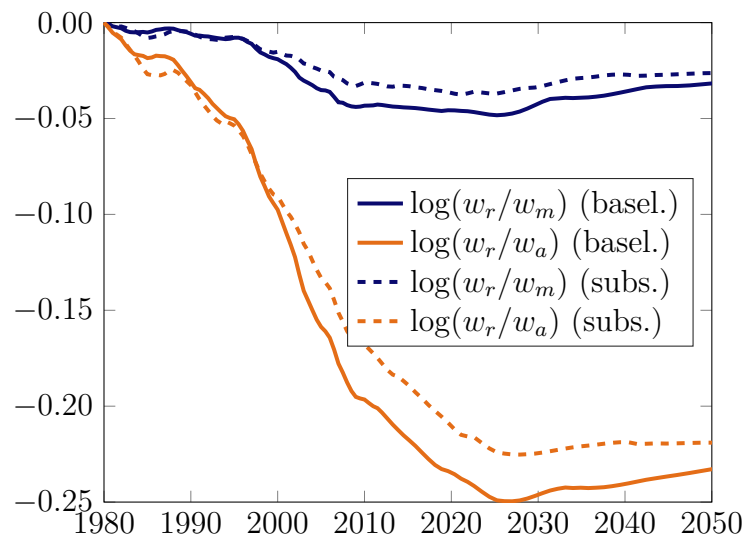


Figure 17: Change in relative wages in the baseline and when the switching subsidy is in place ($\psi = 0.5$), compared to 1980.

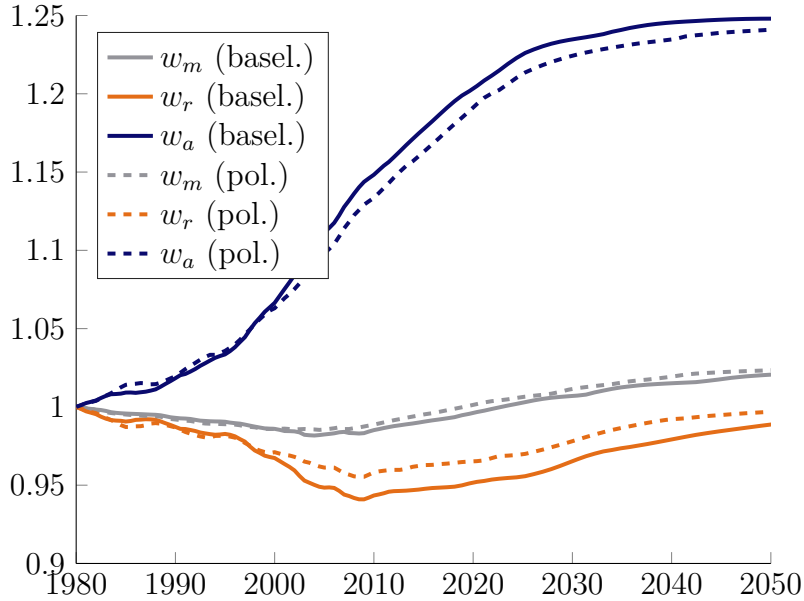


Figure 18: Wages in the baseline and with the switching subsidy ($\psi = 0.5$).

those born in 1980. This is because the manual wage premium w_m rises slightly during the transition due to the policy, as becomes visible in Figure 18, which plots the paths of the three occupational wage premia relative to 1980. This hints at general equilibrium effects of the policy, which lift the wages in the manual occupations, even though these occupations face higher labor supply under the policy.

To understand this more clearly and to see how the proposed policy affects aggregate production, the left panel of Figure 19 plots output Y_t during the transition period with policy relative to output during the baseline transition. In the first years of the transition, the policy tends to reduce output somewhat, which is due to some households taking up the benefit and therefore causing a (small) rise in distortionary taxes. Starting in the mid-2000s, however, output is larger under the transition with policy than under the baseline.⁴⁵ A further decomposition reveals that this is largely due to an increase in the capital stock when the policy is active (see Figure 35 in the appendix).⁴⁶ Since routine labor is highly substitutable with ICT capital, and routine workers are less reluctant to leave their occupations with the subsidy in place, firms demand more ICT capital and the capital stock in the economy rises. From the mid 2000s onward, the economy employs about 2-2.5% more ICT capital under the policy than it does under the baseline transition, as the right panel of Figure 19 demonstrates.

⁴⁵On average, output is 0.05% higher between 1980 and 2050 under the policy compared to the baseline.

⁴⁶It could also be that output is larger under the policy because labor becomes more efficiently allocated across occupations. This effect is however difficult to disentangle from the dampening effect on labor supply caused by the rise in distortionary taxation. As Figure 35 in the appendix shows, this latter effect dominates any positive effect on output caused by a more efficient allocation of workers across occupations.

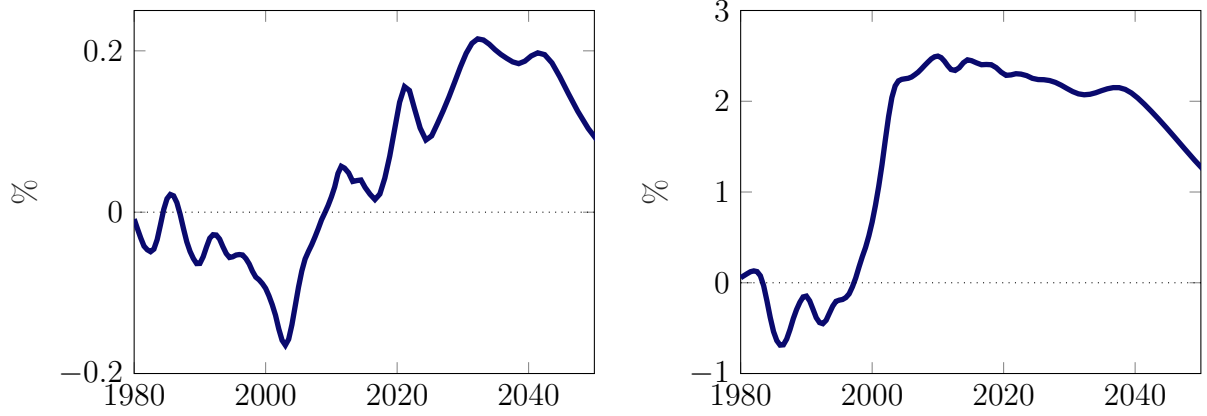


Figure 19: Left panel: Output Y_t . Right panel: ICT capital \tilde{K}_{ict} .

Notes: Both panels show the deviations of values under the policy that introduces a switching subsidy ($\psi = 0.5$) relative to the baseline transition, in %.

6.2 Re-training program

In this section I ask what impact a re-training program, similar to that offered by the DoL's Trade Adjustment Assistance, would have in my model. I interpret the re-training as speeding up the rate at which experienced routine workers, who exit their occupation, accumulate human capital in their new occupation. This brings forward the gains from switching the occupation to experienced routine workers, and thereby shortens the time during which they face low earnings.

I need to calibrate the increased rate $\tilde{\lambda}_h$, at which workers who receive the re-training become experienced, as well as the cost of the re-training. Both of these parameters are difficult to pin down. I therefore opt for the following strategy. The DoL provides information on the average cost of its re-training program in its annual reports to the US Congress. Between 2015 and 2019, the average cost was 13,200\$ (in 2019 \$). Since information on how much this improves earnings growth compared to those workers who do not receive the training, is difficult to obtain, I ask instead what $\tilde{\lambda}_h$ would need to be in order for the program to break even in expectation in terms of its present-value cost and benefit. Formally, I define expected income of an average inexperienced worker in the abstract occupation, given rate λ , as

$$\Omega_y(\lambda) = 0.5 \cdot w_{a,1980} \cdot \phi_a(\bar{s}_{old}) \cdot \Lambda(\lambda) ,$$

where

$$\Lambda(\lambda) = \int_{t=0}^{\infty} e^{-(r_k+\zeta)t} [e^{-\lambda t} \underline{h} + (1 - e^{-\lambda t}) \bar{h}] dt = \frac{\bar{h}}{r_k + \zeta} - \frac{\bar{h} - \underline{h}}{r_k + \zeta + \lambda} .$$

I then search for the $\tilde{\lambda}_h$ that satisfies

$$\Omega_y(\tilde{\lambda}_h) - \Omega_y(\lambda_h) = 13,200\$.$$

The $\tilde{\lambda}_h$ that satisfies this equation is 0.040, which compares to the originally calibrated (lower) rate λ_h of 0.025. Table 5 shows what this implies for expected wage growth. As

Table 5: Expected wage growth for inexperienced workers over different horizons

	1 year	2 years	5 years	10 years
λ_h	2.9%	5.5%	12.0%	19.3%
$\tilde{\lambda}_h$	4.5%	8.3%	16.8%	24.4%

Notes: Expected wage growth for inexperienced workers (\underline{h}), i.e. $(1 - e^{-\lambda \cdot 4 dt}) \cdot (\bar{h}/\underline{h} - 1)$.

before, I assume that the policy is only active until 2040, after which transition rates for all workers are reset to their steady state values. Furthermore, as before, the policy is financed by increasing τ to keep the same level of government expenditures G_t and transfers T_t affordable at all times.

The left panel of Figure 20 demonstrates that while the proposed policy increases welfare, it does so to a smaller extent than the transfer scheme that replaces 50% of lost earnings proposed in the previous subsection. While, similarly as the switching subsidy, the re-training program raises the incentives for experienced routine workers to leave their occupation, it still leaves a considerable time period during which earnings after switching are significantly lower than before switching. The immediate replacement of part of the lost earnings is therefore better at addressing the key friction in the model and incentivizing even hand-to-mouth households to leave the routine occupations (see Figure 37 in the appendix).

6.3 Tax on ICT capital

There has been a recent debate on whether capital that substitutes for certain types of labor should be taxed, and if so, at what rate. Slavík and Yazici (2014) argue that taxes should be relatively higher for types of capital that are relatively substitutable to labor in production, as is the case for ICT capital in my model.⁴⁷ Acemoglu, Manera, et al. (2020) call for taxing capital in tasks in which automation only leads to minor productivity gains. Guerreiro et al. (2020) argue that taxing robots is optimal, at least as long as the transition toward an economy with less demand for routine labor is taking place. However, as increasingly many new cohorts have been able to react to technological change by choosing to work in the abstract occupations, optimal taxes should decline and eventually be zero.

Closest to my framework is Thuemmel (2020). He studies optimal robot taxes in a static Mirrlees model with the same three occupations that also feature in my framework. He argues that while it is in principle optimal to distort robot production, it is a priori unclear whether robots should be taxed or subsidized. The reason is that taxing robots, and thereby raising wages of routine workers relative to manual workers, increases income inequality at the bottom of the wage distribution. He finds that, depending on the parametrisation of his

⁴⁷Kina et al. (2020) furthermore show that optimal taxes on types of capital that substitute for labor, raised to finance re-distribution, can be quite high in incomplete markets models.

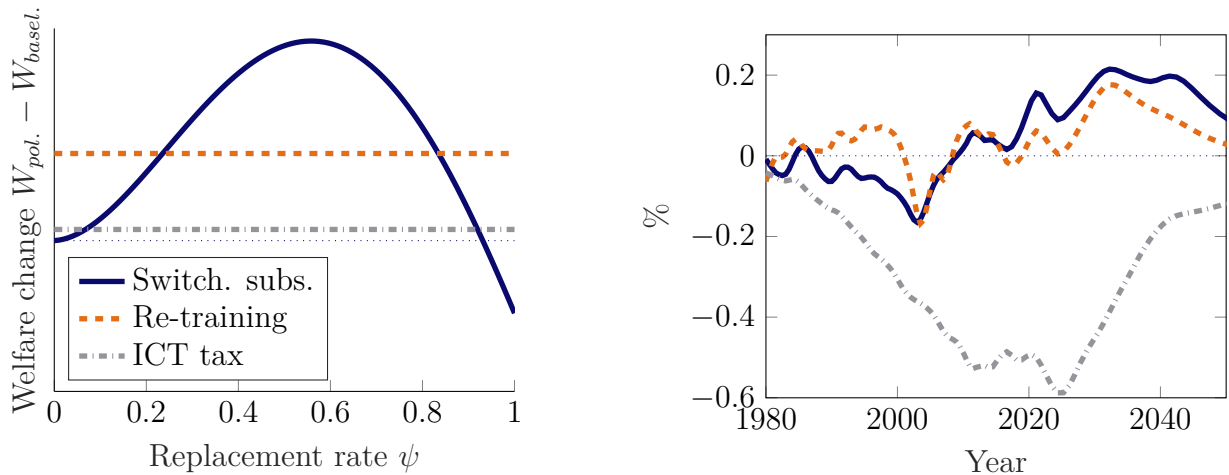


Figure 20: Left panel: Welfare improvements relative to baseline transition. Right panel: Output relative to baseline transition.

Notes: Switching subsidy corresponds to a transfer to experienced routine workers who leave their occupation ($\psi = 0.5$ in the right panel). Re-training corresponds to a government-paid program that speeds up the rate at which formerly experienced routine workers re-gain human capital in their new occupation. ICT tax corresponds to the introduction of a temporary 1% tax on the stock of ICT capital. Left panel: absolute welfare gains of different policies relative to the baseline transition. Right panel: deviations of output under different policies relative to the baseline, in %.

model, the optimal tax on robots lies between -0.5% (i.e. a subsidy) and 1%.

Building on these insights and using the results from Section 4, I implement the following scheme in my model. Starting from the initial steady state, which does not feature a tax on ICT capital, I start raising such a tax in 1980 and incrementally increase it up until it reaches 1% in 2000.⁴⁸ According to the model, this is the year in which the routine wage started to decline significantly, putting pressure on experienced routine workers to switch occupations (see Figure 18). I leave the tax rate at 1% for twenty years and then reduce it back to zero in a linear fashion, in the spirit of Guerreiro et al. (2020)'s dynamic argument. Figure 36 in the appendix plots the evolution of the ICT tax I feed into the model.⁴⁹

The proposed tax on ICT capital, while disincentivizing the accumulation of ICT capital, raises demand for routine labor. Similar to the previously discussed two policies, the ICT tax therefore also increases routine wages relative to wages in the other occupations. However, while the switching subsidy and the re-training program simultaneously encourage experienced routine workers to leave their occupation, the introduction of a tax on ICT capital has no such effect. In sum, and as can be seen in the left panel of Figure 20, the temporary tax on ICT capital indeed raises aggregate social welfare, echoing the results in Guerreiro et al. (2020), Slavík and Yazici (2014), and Thuemmel (2020), though it does so only modestly in

⁴⁸This is a tax on the stock of capital. Given a net interest rate of 7.5%, it corresponds to a tax of $1\% \cdot 1.075/0.075 = 14\%$ on ICT capital income.

⁴⁹In contrast to the previously discussed two policies, levying an ICT tax provides additional revenue for the government, which it uses to lower taxes on labor income, thereby stimulating labor supply.

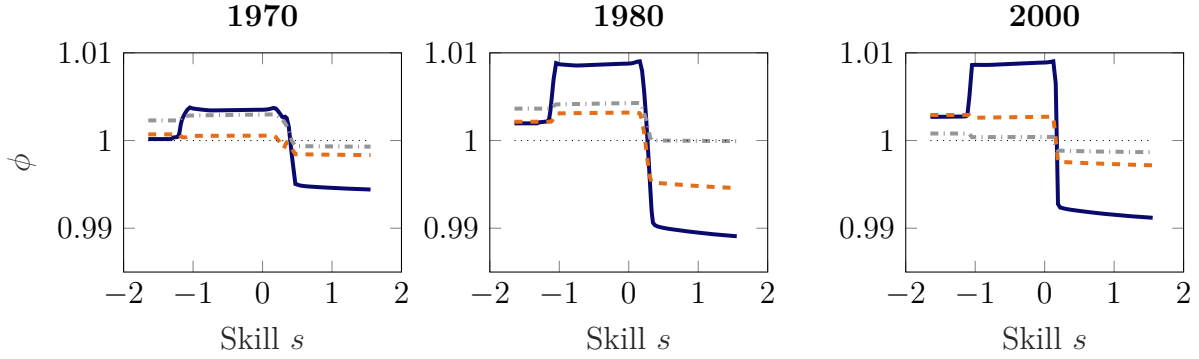


Figure 21: Change in expected lifetime consumption under different policies relative to baseline transition, for different birth cohorts.

Notes: Blue solid: Switching subsidy of $\psi = 50\%$. Orange dashed: Re-training program. Grey dashed: ICT tax. The year denotes the year of birth of a given cohort. ϕ denotes expected lifetime consumption under a policy relative to the baseline transition for workers of a given skill type s , born in a given year.

my model. However, the tax disincentivizes the accumulation of capital and thereby reduces output quite significantly (right panel), which is in contrast to the previous two policies. As a result of this, the cohorts who enter the labor market at a later stage of the transition and do not benefit from the re-distributive effects of the tax, bear the burden of living in an economy with less capital and therefore lower output (Figure 21).

I stress that these results do not speak to the optimality of taxing (ICT) capital per se, especially in the steady state of the model. An ICT tax in the steady state, which I have abstracted from for simplicity, could potentially increase social welfare through its re-distributive effects. Adding labor market frictions to the model, which I have also abstracted from, would provide a further rationale for taxing capital, as Acemoglu, Manera, et al. (2020) show. However, my results indicate that, when viewed merely as an instrument to alleviate the distributional consequences of labor market polarization, raising taxes on ICT capital comes with relatively large output losses and small welfare gains compared to the introduction of switching subsidies or a re-training program.

7 Conclusion

The US labor market has undergone a profound structural change over the recent decades. Caused by a falling price of ICT capital, routine-intensive tasks have been successively automated. As a result of this, the US workforce has reallocated away from occupations intensive in these routine tasks, into occupations that perform work that is more complementary to ICT capital.

I have demonstrated that such a labor market transition is delayed when a large share of households in the economy lives hand-to-mouth, as is the case in the US. When human capital is at least in part tied to the occupation of a worker, their occupational choices become dynamic investment decisions whenever relative occupational wage premia change over time.

In a simplified model, I have highlighted that occupational choices are distorted towards staying in today's attractive occupations when households are hand-to-mouth compared to the case when they are not.

Two groups of households have played a key role in the reshuffling of labor across occupations, namely experienced routine workers and inexperienced workers arriving new to the labor market. Using data from the SCF, I have documented empirically that among both of these groups, the likelihood of being hand-to-mouth is relatively high compared to the average US household.

Building on these insights, I have integrated an exogenous trend in labor market polarization into an incomplete markets model featuring occupation-specific human capital and a realistically high share of households who live hand-to-mouth. In the calibrated model, by one measure, the existence of hand-to-mouth households has caused a lag in labor market polarization by about three years. This has mainly been due to experienced routine workers living hand-to-mouth and not exiting their occupations as fast as similar workers owning a buffer stock of liquid assets.

I have shown that introducing a government subsidy, paid out to those experienced routine workers who have left their occupation, can be welfare-improving. While high-skilled workers lose because of the additional tax burden, medium-skilled workers gain. This gain in part stems from the fact that the proposed policy dampens the supply of routine labor, thereby putting upward pressure on routine wages. However, aggregate welfare improvements are not solely driven by re-distribution, but in part also achieved by higher output under the proposed policy regime. The transfer leads to a lower supply of routine labor and thus to a higher demand of firms for ICT capital, resulting in a rise of the economy's capital stock. As a positive side-effect, the proposed transfer scheme also benefits (low-skilled) manual workers, who never pick up the additional transfers but profit from higher wages in the manual occupations.

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A Details on SCF data

A.1 Mapping occupations between SCF and Autor and Dorn (2013)

Following Jaimovich and Siu (2020), I consider the following three broad groups of occupations, which in turn collect the six groups listed in Autor and Dorn (2013):

- Abstract:
 - management/professional/technical/financial sales/public security occupations
- Routine:
 - administrative support and retail sales occupations
 - precision production and craft occupations
 - machine operators, assemblers and inspectors
 - transportation/construction/mechanics/mining/agricultural occupations
- Manual:
 - low-skill services

From 1989 until 2001, the SCF used the 3-digit 1980 and 1990 Census occupation codes, which were both very similar. The public-use files contain identifiers for whether the household head worked in one of six broad occupational groups. I map these six groups as closely as possible to the three groups listed above using the consistent occupation-classification scheme proposed in the data appendix of Dorn (2009) (*Occ1990dd*).

Table 6 lists the assignment of SCF groups to the three broad occupational groups. While the overlap is very large and the assignment therefore unambiguous for the SCF groups 1 and 3 to 6, group 2 contains some abstract and some routine occupations (codes 203-389 of the 1980 Census classification). I therefore further look at the employment shares in each of these occupations provided by Autor and Dorn (2013) for the years 1990 and 2000. A significantly smaller fraction of workers in this group was employed in abstract occupations (8-9%, codes 203-258) than in routine occupations (21-22%, codes 274-389). Hence, I classify all workers of group 2 as routine, which also explains why I slightly overestimate the routine employment share in Figure 1 in the first years.

Broad Group	Manual	Routine	Abstract
SCF occupation dummies	3	2, 4, 5, 6	1

Table 6: Mapping of SCF occupation dummies into broad occupational groups.

From 2004 onward, the SCF used the 2000 and 2010 Census codes, which were very similar to each other but quite distinct from the earlier Census codes. The SCF then assigned households again into six broad groups. While the overlap between the three broad occupational groups and the six SCF groups is somewhat weaker than prior to 2004, I still find that the assignment displayed in Table 6 yields the closest mapping.

A.2 Details on hand-to-mouth status

Following Kaplan, Violante, et al. (2014), I define the liquid asset holdings of a household m_{it} as the sum of cash, money market accounts, checking/savings/call accounts, prepaid cards, directly held stocks, bonds, non-money-market mutual funds, minus revolving consumer debt. Income y_{it} collects labor earnings, regular private transfers (e.g. child support, alimony), and public transfers (e.g. unemployment benefits, food stamps, Social Security Income). Income y_{it} corresponds to bi-weekly income, as this is the most common frequency of payment in the US (Kaplan, Violante, et al., 2014).

Households are considered hand-to-mouth if and only if one of the following two conditions is true:

$$0 \leq m_{it} \leq \frac{y_{it}}{2}$$

or

$$m_{it} \leq \frac{y_{it}}{2} - \underline{m}_{it},$$

where \underline{m}_{it} corresponds to a household's borrowing constraint, which, in line with Kaplan, Violante, et al. (2014)'s baseline definition, I assume to be one times monthly income.

B Proofs for simple model

B.1 Proofs of Propositions 1 and 2

Unconstrained households I first proof the result regarding the unconstrained households of Proposition 1.

For the household to choose the abstract occupation in period one, it must hold that option 3 yields higher lifetime income than the maximum of options 1 and 2, i.e.

$$\underline{h} + \frac{1}{1+r} \max\{\bar{h}, \omega \underline{h}\} \leq \underline{h}/\omega + \frac{\omega}{1+r} \bar{h}$$

Case 1: $\bar{h}/\underline{h} \geq \omega$

$$\begin{aligned} \underline{h} + \frac{1}{1+r} \bar{h} &\leq \underline{h}/\omega + \frac{\omega}{1+r} \bar{h} \\ (1+r) \left(1 - \frac{1}{\omega}\right) &\leq (\omega - 1) \bar{h}/\underline{h} \\ 1+r &\leq \frac{\omega - 1}{1 - \frac{1}{\omega}} \bar{h}/\underline{h} = \omega \bar{h}/\underline{h} = \omega (\bar{h}/\underline{h} - 1) \frac{\bar{h}/\underline{h}}{\bar{h}/\underline{h} - 1} \end{aligned}$$

Case 2: $\bar{h}/\underline{h} < \omega$

$$\begin{aligned}\underline{h} + \frac{\omega}{1+r}\underline{h} &\leq \underline{h}/\omega + \frac{\omega}{1+r}\bar{h} \\ (1+r)\left(1 - \frac{1}{\omega}\right) &\leq \omega(\bar{h}/\underline{h} - 1) \\ 1+r &\leq \omega \frac{\bar{h}/\underline{h} - 1}{1 - \frac{1}{\omega}} = \omega(\bar{h}/\underline{h} - 1) \frac{\omega}{\omega - 1}\end{aligned}$$

Rearranging yields the desired result. The proof of Proposition 2 regarding the unconstrained households follows analogously.

It is also straightforward to verify that whenever the unconstrained household chooses option 3, she borrows against future income. To see this, note that consumption in period one is $c_1 = \frac{1}{1+\beta} \left(\underline{h}/\omega + \frac{\omega}{1+r}\bar{h} \right)$, and hence savings in period one are $s = \frac{1}{1+\beta} \left(\beta \underline{h}/\omega - \frac{\omega}{1+r}\bar{h} \right)$. Assume for a contradiction that savings in period one are positive

Case 1: $\bar{h}/\underline{h} \geq \omega$

$$\begin{aligned}\beta \underline{h}/\omega &> \frac{\omega}{1+r}\bar{h} \\ \Rightarrow \underline{h}/\omega &> \frac{\omega}{1+r}\bar{h} \\ \Rightarrow 1+r &> \omega^2 \bar{h}/\underline{h} > \omega \bar{h}/\underline{h} \quad \text{✗}\end{aligned}$$

Case 2: $\bar{h}/\underline{h} < \omega$

$$\begin{aligned}\beta \underline{h}/\omega &> \frac{\omega}{1+r}\bar{h} \\ \Rightarrow \underline{h}/\omega &> \frac{\omega}{1+r}\bar{h} \\ \Rightarrow 1+r &> \omega^2 \bar{h}/\underline{h} > \omega^2 \frac{\bar{h}/\underline{h} - 1}{\omega - 1} = \omega \frac{\bar{h}/\underline{h} - 1}{1 - \frac{1}{\omega}} \quad \text{✗}\end{aligned}$$

Constrained households Next I proof the result concerning the constrained households of Proposition 1.

For the household to find it optimal to choose option 3, it must hold that

$$\ln(\underline{h}) + \beta \max \left\{ \ln(\bar{h}), \ln(\omega \underline{h}) \right\} \leq \ln(\underline{h}/\omega) + \beta \ln(\omega \bar{h})$$

Case 1: $\bar{h}/\underline{h} \geq \omega$

$$\begin{aligned}\ln(\underline{h}) + \beta \ln(\bar{h}) &\leq \ln(\underline{h}) - \ln(\omega) + \beta \ln(\omega) + \beta \ln(\bar{h}) \\ 0 &\leq \beta - 1 \quad \text{✗}\end{aligned}$$

The contradiction follows from the fact that I have assumed (strict) discounting, i.e. $\beta < 1$.

Case 2: $\bar{h}/\underline{h} < \omega$

$$\begin{aligned}\ln(\underline{h}) + \beta \ln(\omega) + \beta \ln(\underline{h}) &\leq \ln(\underline{h}) - \ln(\omega) + \beta \ln(\omega) + \beta \ln(\bar{h}) \\ \ln(\omega) &\leq \beta \ln(\bar{h}/\underline{h}) \\ \omega &\leq (\bar{h}/\underline{h})^\beta \quad \text{✗}\end{aligned}$$

Rearranging yields the desired result. The proof of Proposition 2 regarding the unconstrained households follows analogously.

B.2 Mean-reverting productivity

Consider now the introduction of an additional variable $Z > 1$ that augments all wages in period two, i.e.

$$\begin{aligned} w_{r,t=1} &= 1, & w_{r,t=2} &= Z \\ w_{a,t=1} &= \frac{1}{\omega}, & w_{a,t=2} &= Z\omega \end{aligned}$$

The following proposition holds, and can be proved analogously to Proposition 1 above.

Proposition 3. *In $t = 1$, unconstrained households choose the abstract occupation iff*

$$\frac{1+r}{Z} \leq \omega(\bar{h}/\underline{h} - 1) \min \left\{ \frac{\bar{h}/\underline{h}}{\bar{h}/\underline{h} - 1}, \frac{\omega}{\omega - 1} \right\}.$$

In this case, unconstrained households are net borrowers in $t = 1$.

Hand-to-mouth households never choose the abstract occupation in $t = 1$.

This result is exactly identical to Proposition 1, except for the fact that the gross interest rate $(1+r)$ is dampened by the factor Z . Put differently, a higher Z makes choosing the abstract occupations today more likely for the unconstrained households. Intuitively, if wages today are relatively low compared to tomorrow, the opportunity cost of choosing the abstract occupation today is also relatively low.

This can be interpreted in two ways. First, Z could capture aggregate productivity. A recession would therefore, everything else equal, induce more workers to leave the routine occupations. This is in line with empirical evidence on the business cycle patters of the aggregate decline in routine labor (Hershbein and Kahn, 2018; Jaimovich and Siu, 2020).⁵⁰ Second, Z could capture mean-reverting idiosyncratic productivity. This explains the effect, discussed in Section 4, that hand-to-mouth households at some point become more willing than non-hand-to-mouth households to leave the routine occupations, as the former group systematically features a higher share of households with a currently low realization of productivity than the latter group.

⁵⁰Note that the share of hand-to-mouth households in the US economy does not display any notable countercyclical pattern, cf. Figure 2. One should therefore not expect a significantly larger share of hand-to-mouth households during recessions than during booms. The cyclical patterns of the hand-to-mouth share have so far, to the best of my knowledge, not been studied in detail.

C Details of the full model

C.1 FOCs of the representative firm

$$w_m = K_s^\alpha (1 - \alpha) \tilde{Y}^{-\alpha} \mu_m \left(\frac{\tilde{Y}}{N_m} \right)^{\frac{1}{\gamma_m}} \quad (6)$$

$$w_r = \Omega (1 - \mu_a) R^{\frac{\gamma_a - \gamma_r}{\gamma_a \gamma_r}} \mu_r N_r^{\frac{-1}{\gamma_r}} \quad (7)$$

$$w_a = \Omega \mu_a N_a^{\frac{-1}{\gamma_a}} \quad (8)$$

$$r_{ict} = \Omega (1 - \mu_a) R^{\frac{\gamma_a - \gamma_r}{\gamma_a \gamma_r}} (1 - \mu_r) K_{ict}^{\frac{-1}{\gamma_r}} \quad (9)$$

$$r_s = \alpha K_s^{\alpha-1} \tilde{Y}^{1-\alpha} \quad (10)$$

where

$$\Omega = K_s^\alpha (1 - \alpha) \tilde{Y}^{\frac{-\alpha}{\gamma_m}} (1 - \mu_m) \left(\mu_a N_a^{\frac{\gamma_a - 1}{\gamma_a}} + (1 - \mu_a) R^{\frac{\gamma_a - 1}{\gamma_a}} \right)^{\frac{\gamma_m - \gamma_a}{(\gamma_a - 1) \gamma_m}}$$

$$\tilde{Y} = \left[\mu_m N_m^{\frac{\gamma_m - 1}{\gamma_m}} + (1 - \mu_m) \left[\mu_a N_a^{\frac{\gamma_a - 1}{\gamma_a}} + (1 - \mu_a) R^{\frac{\gamma_a - 1}{\gamma_a}} \right]^{\frac{\gamma_a (\gamma_m - 1)}{(\gamma_a - 1) \gamma_m}} \right]^{\frac{\gamma_m}{\gamma_m - 1}}$$

C.2 Hamilton-Jacobi-Bellman equation

The solution to the workers' problem is characterized by

$$\begin{aligned} (\rho + \zeta) V_t(s, \hat{z}, h, j, b, \tilde{k}) &= \max_{c, \ell, \tilde{j}, d} u(c, \ell) \\ &+ V_{b,t}(s, \hat{z}, h, j, b, \tilde{k}) \left[(1 - \tau) w \ell z h \phi_j(s) + r^b(b) b + T - d - \chi(d, \tilde{k}) - c \right] \\ &+ V_{\tilde{k},t}(s, \hat{z}, h, j, b, \tilde{k}) (r_k \tilde{k} + d) \\ &+ \sum_{q \in \{1, 2\}} V_{\hat{z},t}(s, \hat{z}, h, j, b, \tilde{k}) (-\beta_{z,q} \hat{z}_q) \\ &+ \lambda_{z,q} \int_{-\infty}^{\infty} (V_t(s, x, h, j, b, \tilde{k}) - V_t(s, \hat{z}_q, h, j, b, \tilde{k})) \phi(x) dx \\ &+ \dot{V}_t(s, \hat{z}, h, j, b, \tilde{k}) \end{aligned}$$

with $\phi(\cdot)$ denoting the pdf of a standard normal distribution, and the following constraint holding $\forall \tilde{j} \neq j \in \{m, r, a\}$:

$$V(s, \hat{z}, h, j, b, \tilde{k}) \geq V(s, \hat{z}, h, \tilde{j}, b, \tilde{k}) .$$

Note that in steady state, j is a redundant state variable, as occupational choice is perfectly predicted by skill type s (see discussion in the main text). I can therefore employ the methods outlined in Achdou et al. (2020) to solve the household problem without having to take care of any stopping time problem arising from occupational choice.

During the transition, j does become a non-redundant idiosyncratic state variable. However, to solve for the transition, I discretize time into many finite points (Kaplan, Moll, et al., 2018). This allows me to compare, at each point on the time grid, the value from working in either of the three occupational groups.

C.3 Short-run impact of falling relative price of ICT capital

What is the effect of a falling relative price of ICT capital (a rise in q_{ict}) on wages and the interest rate? To develop an answer, remember that the production function (1) can be written with capital expressed in units of the final (consumption) good:

$$Y = F(N_m, N_r, N_a, q_{ict}\tilde{K}_{ict}, K_s)$$

Here, I use the assumption that the relative price q_s of non-ICT capital is one at all times. In this section, let \tilde{r}_{ict} denote the interest rate on price-adjusted ICT capital \tilde{K}_{ict} , such that $\tilde{r}_{ict} = q_{ict}F_{\tilde{K}_{ict}}(N_m, N_r, N_a, q_{ict}\tilde{K}_{ict}, K_s)$. The following proposition holds⁵¹

Proposition 4. *Consider the impact of a change in q_{ict} in the short term, i.e. assuming that factor inputs $N_m, N_r, N_a, \tilde{K}_{ict}$, and K_s do not adjust. The impact of a change in q_{ict} on wages and the rental rate of ICT capital is given by:*

$$\frac{d \ln w_i}{d \ln q_{ict}} = \frac{1 - s_i}{\epsilon_{\tilde{K}_{ict}N_i}} - \frac{s_j}{\epsilon_{\tilde{K}_{ict}N_j}} - \frac{s_h}{\epsilon_{\tilde{K}_{ict}N_h}} - \frac{s_{K_s}}{\epsilon_{\tilde{K}_{ict}K_s}} \quad (\text{P.1a})$$

$$\frac{d \ln \tilde{r}_{ict}}{d \ln q_{ict}} = 1 - \frac{s_i}{\epsilon_{\tilde{K}_{ict}N_i}} - \frac{s_j}{\epsilon_{\tilde{K}_{ict}N_j}} - \frac{s_h}{\epsilon_{\tilde{K}_{ict}N_h}} - \frac{s_{K_s}}{\epsilon_{\tilde{K}_{ict}K_s}} \quad (\text{P.1b})$$

where I define the elasticity of substitution of the respective factor input with ICT capital as

$$\epsilon_{\tilde{K}_{ict}X} = -\frac{d \ln(\tilde{K}_{ict}/X)}{d \ln(F_{\tilde{K}_{ict}}/F_X)} \quad (11)$$

and the shares of income as

$$s_i = \frac{w_i N_i}{Y}, \quad s_{\tilde{K}_{ict}} = \frac{\tilde{r}_{ict} \tilde{K}_{ict}}{Y}, \quad s_{K_s} = \frac{r_s K_s}{Y}.$$

Proof. Rewrite (11) as

$$\epsilon_{\tilde{K}_{ict}N_i}(d \ln F_{\tilde{K}_{ict}} - d \ln F_{N_i}) = -\left(d \ln(q_{ict}\tilde{K}_{ict}) - d \ln(N_i)\right)$$

Using the facts that in the short run $d \ln \tilde{r} = d \ln F_{\tilde{K}_{ict}} + d \ln q_{ict}$, $d \ln w_i = d \ln F_{N_i}$, and $d \ln \tilde{K}_{ict} = d \ln K_s = d \ln N_i = 0$, we have that

$$\begin{aligned} \epsilon_{\tilde{K}_{ict}N_i}(d \ln \tilde{r}_{ict} - d \ln q_{ict} - d \ln F_{N_i}) &= -(d \ln q_{ict}) \\ (d \ln w_i - d \ln \tilde{r}_{ict})\epsilon_{\tilde{K}_{ict}N_i} &= (1 - \epsilon_{\tilde{K}_{ict}N_i}) d \ln q_{ict} \end{aligned} \quad (12)$$

⁵¹The exposition and proofs follow along the lines of Acemoglu and Restrepo (2018a).

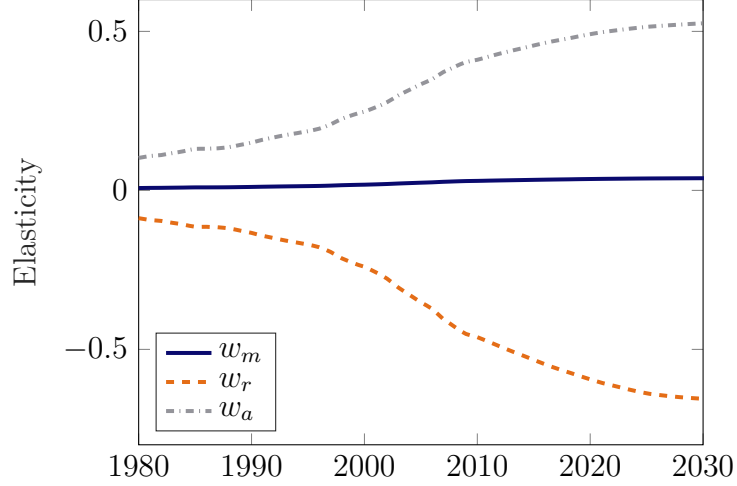


Figure 22: Short-run wage elasticities $\frac{d \ln w_i}{d \ln q_{ict}}$.

We further have that because of constant returns to scale

$$\begin{aligned}
 Y &= w_a N_a + w_r N_r + w_m N_m + \tilde{r}_{ict} \tilde{K}_{ict} + r_s K_s \\
 dY &= dw_a N_a + dw_r N_r + dw_m N_m + d\tilde{r}_{ict} \tilde{K}_{ict} + dr_s K_s \quad | : Y \\
 \frac{dq_{ict}}{q_{ict}} \frac{q_{ict} F_{\tilde{K}_{ict}} \tilde{K}_{ict}}{Y} &= dw_a \frac{s_{N_a}}{w_a} + dw_r \frac{s_{N_r}}{w_r} + dw_m \frac{s_{N_m}}{w_m} + d\tilde{r}_{ict} \frac{s_{\tilde{K}_{ict}}}{\tilde{r}_{ict}} + dr_s \frac{s_{K_s}}{r_s} \\
 d \ln q_{ict} s_{\tilde{K}_{ict}} &= d \ln w_a s_{N_a} + d \ln w_r s_{N_r} + d \ln w_m s_{N_m} + d \ln \tilde{r}_{ict} s_{\tilde{K}_{ict}} + d \ln r_s s_{K_s} \quad (13)
 \end{aligned}$$

Combining (12) and (13) yields (P.1a) and (P.1b). \square

Figure 22 reports the wage elasticities over time using the calibrated values of the production function and the factor inputs from the aseline transition. Since routine labor is highly complementary to ICT capital, its wage rate falls when q_{ict} rises. This stands in contrast to wages in manual and abstract occupations, which both perform work that is relatively substitutable to ICT capital. As can be seen, the magnitudes of the elasticities grow over time, as ICT capital becomes more important in production. For instance, a one percent increase in q_{ict} leads to a fall in w_r of 0.09 percent in 1980, and of 0.68 percent in the final steady state.

C.4 Computation of counterfactual densities

To compute the counterfactual densities of Section 4 I proceed as follows. I start with the distribution of households over the state space $\Gamma(i)$ in the initial steady state. Denote the

densities in 1980 for each skill type \tilde{s} as follows:

$$\begin{aligned}
g_{1980,y,m,\tilde{s}} &= \int_{i:\{h=\underline{h}\wedge s=\tilde{s}\}} \mathbf{1}_{\{j^*(i)=m\}} d\Gamma(i) \\
g_{1980,y,r,\tilde{s}} &= \int_{i:\{h=\underline{h}\wedge s=\tilde{s}\}} \mathbf{1}_{\{j^*(i)=r\}} d\Gamma(i) \\
g_{1980,y,a,\tilde{s}} &= \int_{i:\{h=\underline{h}\wedge s=\tilde{s}\}} \mathbf{1}_{\{j^*(i)=a\}} d\Gamma(i) \\
g_{1980,o,m,\tilde{s}} &= \int_{i:\{h=\bar{h}\wedge s=\tilde{s}\}} \mathbf{1}_{\{j^*(i)=m\}} d\Gamma(i) \\
g_{1980,o,r,\tilde{s}} &= \int_{i:\{h=\bar{h}\wedge s=\tilde{s}\}} \mathbf{1}_{\{j^*(i)=r\}} d\Gamma(i) \\
g_{1980,o,a,\tilde{s}} &= \int_{i:\{h=\bar{h}\wedge s=\tilde{s}\}} \mathbf{1}_{\{j^*(i)=a\}} d\Gamma(i) ,
\end{aligned}$$

where $j^*(i)$ denotes optimal occupational choices in the initial steady state, and y and o in the index of the densities abbreviates “young” (inexperienced) and “old” (experienced), respectively. $\mathbf{1}_{\{\cdot\}}$ denotes the indicator function.

For each new point in time t , I then compute for each skill type \tilde{s} the average probability across all inexperienced households to choose a certain occupation \tilde{j} , and denote this probability by $p_{t,\tilde{s},\tilde{j}}$, i.e.

$$p_{t,\tilde{s},\tilde{j}} = \frac{\int_{i:\{h=\underline{h}\wedge s=\tilde{s}\}} \mathbf{1}_{\{j_t^*=\tilde{j}\}} d\Gamma_t(i)}{\int_{i:\{h=\underline{h}\wedge s=\tilde{s}\}} d\Gamma_t(i)} \quad (14)$$

This effectively averages over the wealth (b and \tilde{k}) and idiosyncratic productivity (z) dimensions, while conditioning on human capital and skill type. Γ_t refers to the true distribution at time t during the baseline transition. Similarly, for $j \in \{m, r, a\}$, I compute the average probability $x_{t,\tilde{s},j}$ that experienced households exit their current occupation j and become inexperienced households

$$x_{t,\tilde{s},j} = \frac{\int_{i:\{j_{t-1}^*=j\wedge h=\bar{h}\wedge s=\tilde{s}\}} \mathbf{1}_{\{j_t^*\neq j\}} d\Gamma_t(i)}{\int_{i:\{j_{t-1}^*=j\wedge h=\bar{h}\wedge s=\tilde{s}\}} d\Gamma_t(i)} \quad (15)$$

I then use these probabilities to iterate forward the densities of skill type \tilde{s} in the following way. For inexperienced households in occupation j :

$$\begin{aligned}
g_{t+1,y,j,\tilde{s}} &= p_{t,\tilde{s},j} \left\{ \underbrace{e^{-\lambda_h \cdot dt} \sum_{k \in \{m,r,a\}} g_{t,y,k,\tilde{s}}}_{\text{inexp. HHs who do not become experienced}} \right. \\
&\quad + \underbrace{\sum_{k \in \{m,r,a\}} \left[x_{t,\tilde{s},k} \left(e^{-\zeta \cdot dt} g_{t,o,k,\tilde{s}} + (1 - e^{-\lambda_h \cdot dt}) g_{t,y,k,\tilde{s}} \right) \right]}_{\text{exp. HHs who exit their occ.}} \\
&\quad \left. + (1 - e^{-\zeta \cdot dt}) \underbrace{\sum_{k \in \{m,r,a\}} g_{t,o,k,\tilde{s}}}_{\text{dead exp. HHs}} \right\} \quad (16)
\end{aligned}$$

And for experienced households in occupation j :

$$g_{t+1,o,j,\tilde{s}} = (1 - x_{t,\tilde{s},j}) \left\{ e^{-\zeta \cdot dt} g_{t,o,j,\tilde{s}} + (1 - e^{-\lambda_h \cdot dt}) g_{t,y,j,\tilde{s}} \right\} \quad (17)$$

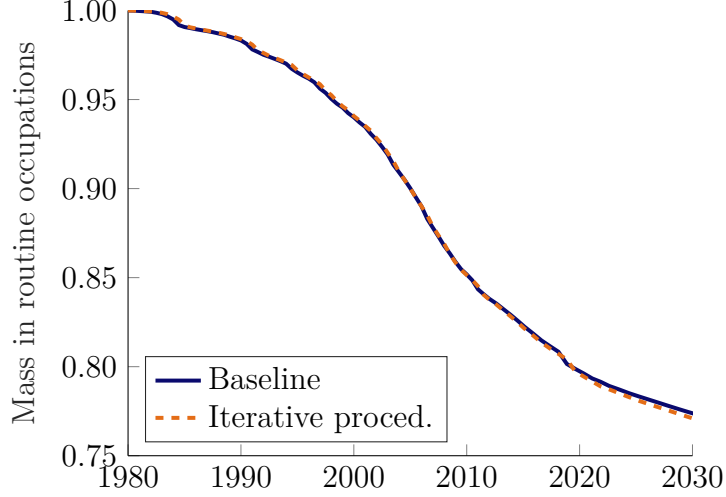


Figure 23: Mass of households employed in routine occupations (1980=1).

Notes: Blue solid: true mass during the transition ($\int_{i:j_t^*=r} d\Gamma_t(i)$). Orange dashed: mass constructed from iterative procedure ($\sum_s g_{t,y,r,s} + g_{t,o,r,s}$).

The last step is to aggregate these densities across all skill types s .

Figure 23 plots both the actual mass of households in the routine occupations (i.e. using the Γ_t), as well as the one obtained from the iterative procedure described here. It reveals that by using the iterative procedure I recover the actual distributions during the transition very well.

Figure 10 In both counterfactuals, I set all exit probabilities $x_{t,s,j} = 0$ in (16) and (17). Furthermore, for computing the grey line (all inexperienced households optimally choose their occupation at all times) (16) is left unchanged, besides the aforementioned fact that all $x_{t,s,j} = 0$. For computing the orange line (only new-borns allowed to choose occupation) (16) becomes

$$g_{t+1,y,j,\tilde{s}} = e^{-\zeta \cdot dt} e^{-\lambda_h \cdot dt} g_{t,y,j,\tilde{s}} + p_{t,\tilde{s},j} (1 - e^{-\zeta \cdot dt}) \sum_{k \in \{m,r,a\}} [g_{t,o,k,\tilde{s}} + e^{-\lambda_h \cdot dt} g_{t,y,k,\tilde{s}}] .$$

Figure 12 To arrive at the counterfactual distribution using policy functions of hand-to-mouth households only, as in Figure 12, I replace $\Gamma_t(i)$ in (14) and (15) by

$$\Gamma_t(i) \cdot \mathbf{1}_{i:\{b=0 \vee b=-b\}} .$$

I then iterate on (16) and (17) as described above. As Figure 12 plots effective labor, and not the mass of routine labor, I multiply the corresponding masses by

$$h \cdot l^* \cdot \phi_j(\tilde{s}) ,$$

where l^* is the average labor supply of the respective type, obtained in an analogous fashion to the probabilities p and x above.

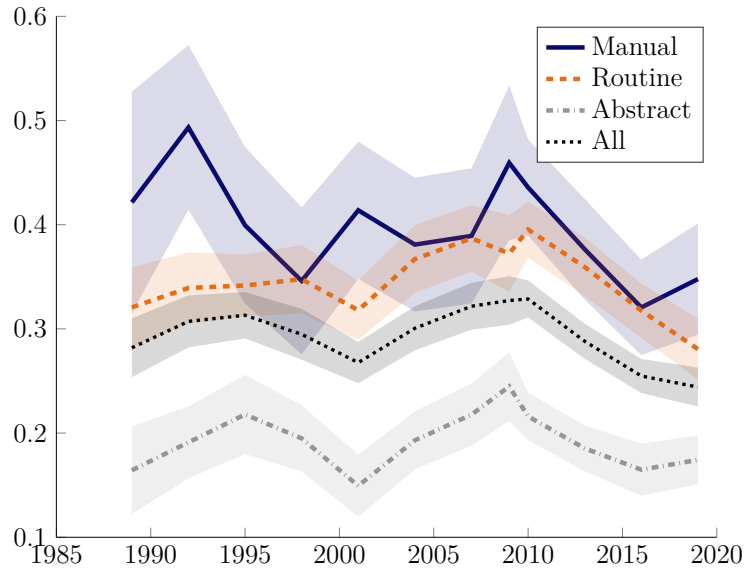


Figure 24: Hand-to-mouth shares in the three broad occupational groups. Confidence intervals are at the 95% level.

Table 7: Parameters of the Income Process

	$\beta_{z,j}$	$\lambda_{z,j}$	$\sigma_{z,j}$
$j = 1$	0.761	0.080	1.74
$j = 2$	0.009	0.007	1.53

D Additional graphs and tables

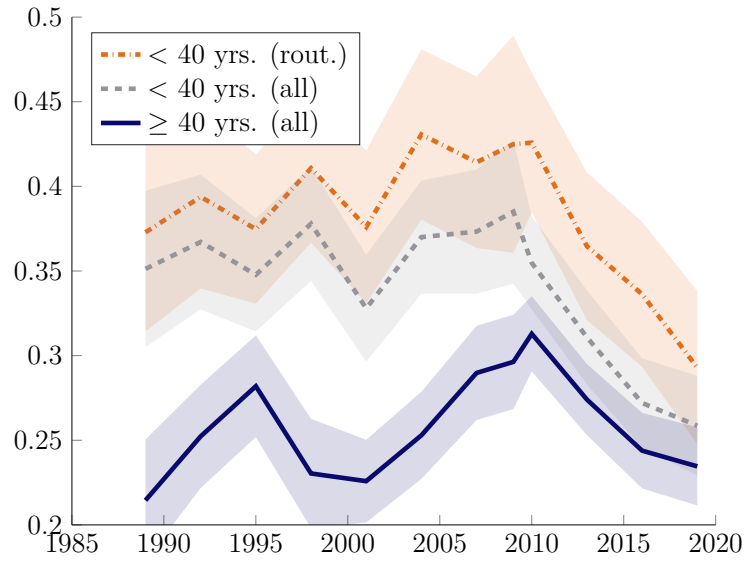


Figure 25: Hand-to-mouth shares by age of household head.

Notes: (all) corresponds to households employed in any of the three broad occupational groups, (rout.) only to those employed in routine occupations. Confidence intervals are at the 95% level.

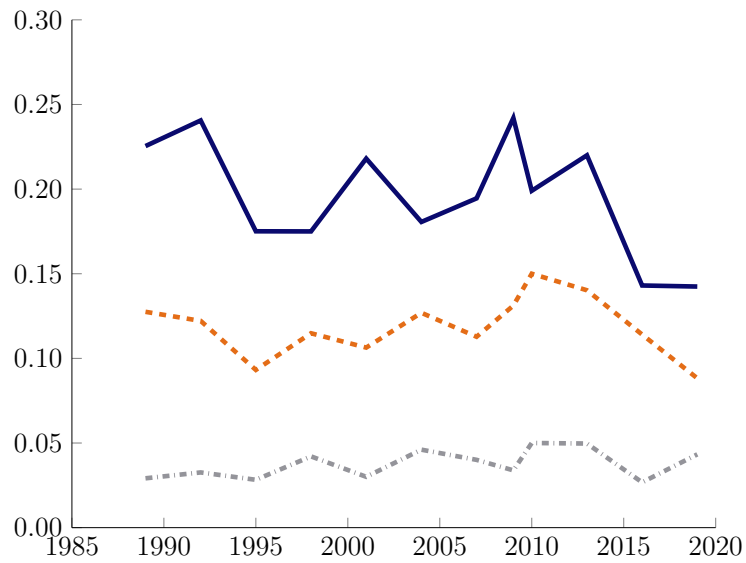


Figure 26: Poor hand-to-mouth shares conditional on broad occupational groups.

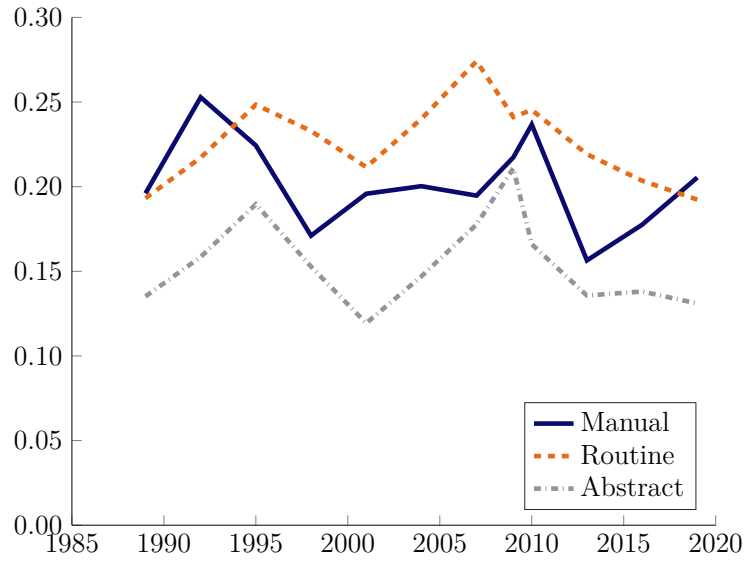


Figure 27: Wealthy hand-to-mouth shares conditional on broad occupational groups.

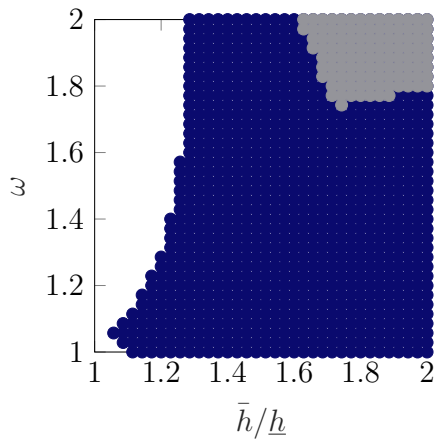


Figure 28: Occupational choices in $t = 1$ of unconstrained households in the simplified model of Section 3 ($r = 10\%$).

Notes: Blue: unconstr. inexperienced workers choose abstract occupation. Grey: Both unconstr. inexperienced and unconstr. experienced routine workers choose abstract occupation.

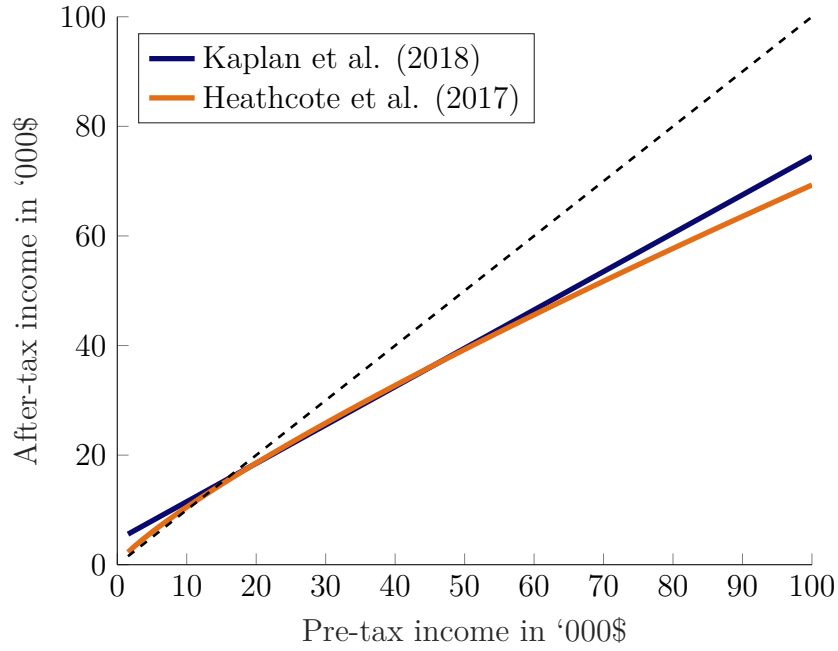


Figure 29: Annual pre-tax and post-tax income in Kaplan, Moll, et al. (2018) and Heathcote et al. (2017).

Notes: Disposable income is $\tilde{y} = (1 - \tau)y + T$ in Kaplan, Moll, et al. (2018). It is $\tilde{y} = \lambda_H y^{1 - \tau_H}$ in Heathcote et al. (2017), where I set $\lambda_H = 5.568$ and $\tau_H = 0.181$, as in Thuemmel (2020).

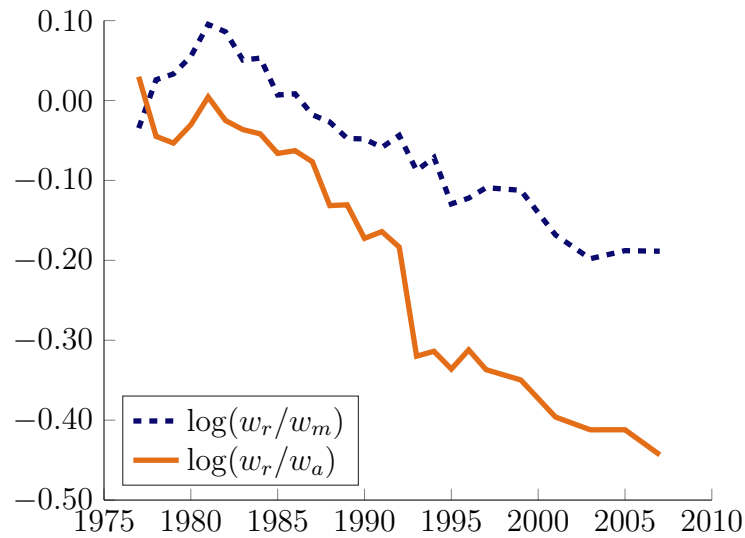


Figure 30: Estimated coefficients on occupation-year fixed effects in PSID (1968-2007) (Cortes, 2016).

Notes: Numbers are adjusted to correspond to routine to manual, and routine to abstract wages.

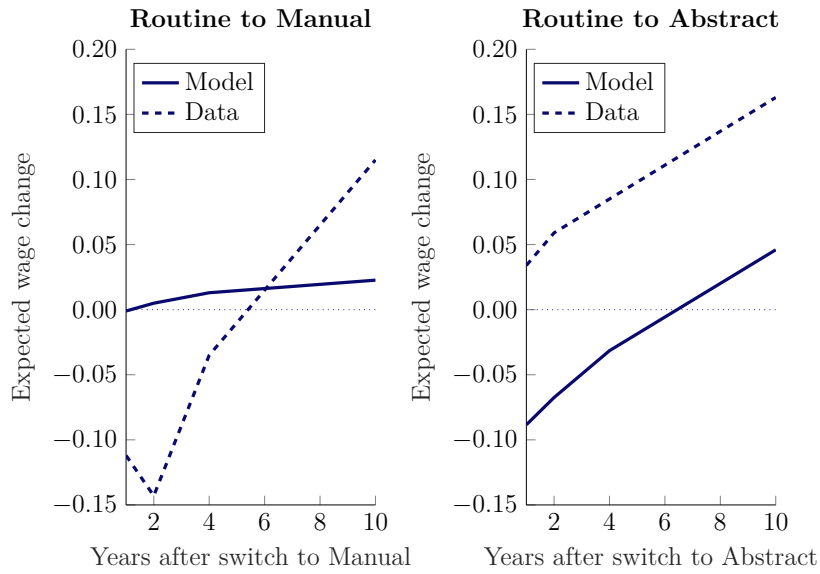


Figure 31: Expected losses in hourly wages. Data are from Cortes (2016).

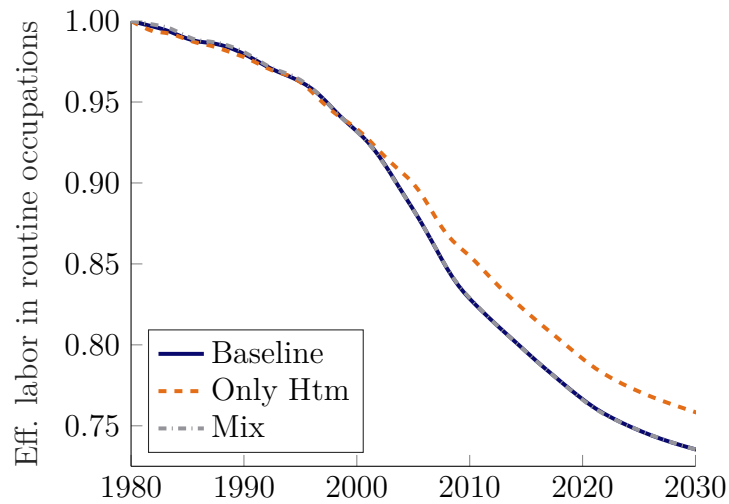


Figure 32: Effective labor in routine occupations (1980=1).

Notes: The orange dashed line uses average policy functions only of the hand-to-mouth households for occupational choices along the transition. “Mix” uses average policy functions of all households for occupational choices of the experienced workers, and those of the hand-to-mouth households for occupational choices of the inexperienced workers.

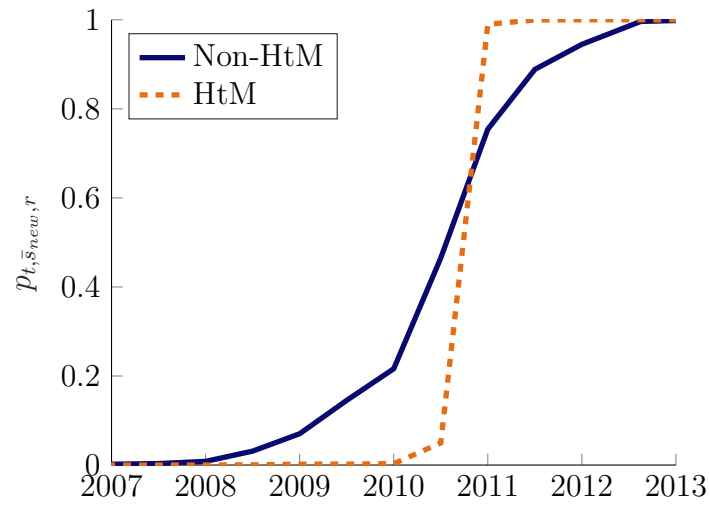


Figure 33: Average probability of inexperienced workers with $s = \bar{s}_{new}$ to enter the routine occupations.

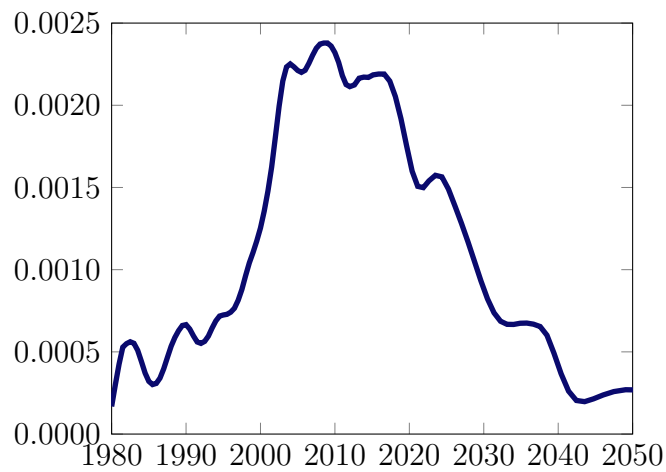


Figure 34: Increase in τ necessary to finance the policy with $\psi = 0.5$. The steady state value of τ is 0.3.

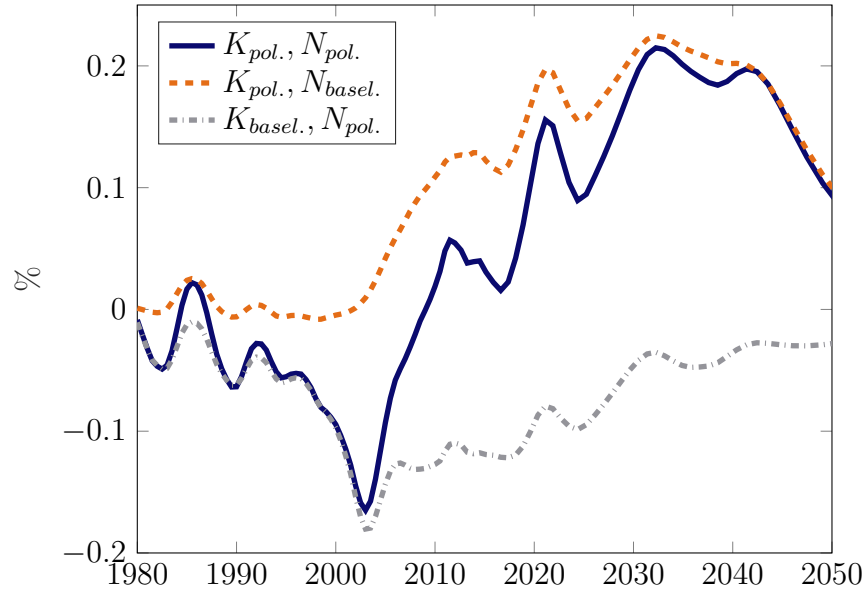


Figure 35: Deviation of output during the transition with policy ($\psi = 0.5$) from output in the baseline transition, in %.

Notes: Blue solid: $F(K_{policy}, N_{policy})$, orange dashed: $F(K_{policy}, N_{baseline})$, grey dashed: $F(K_{baseline}, N_{policy})$, all relative to $F(K_{baseline}, N_{baseline})$.

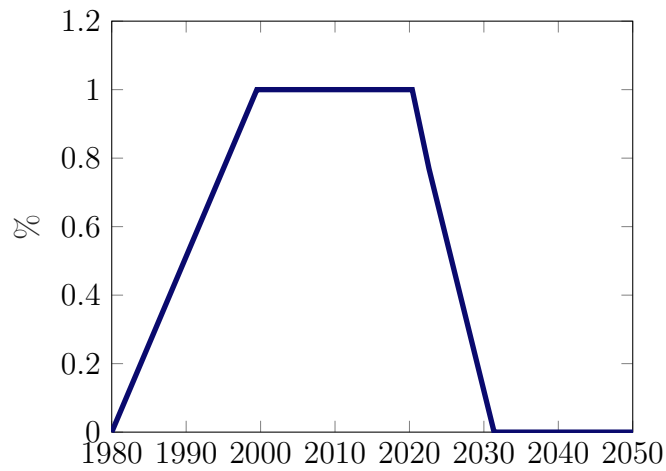


Figure 36: Tax rate on the stock of ICT capital \tilde{K}_{ict} , in %.

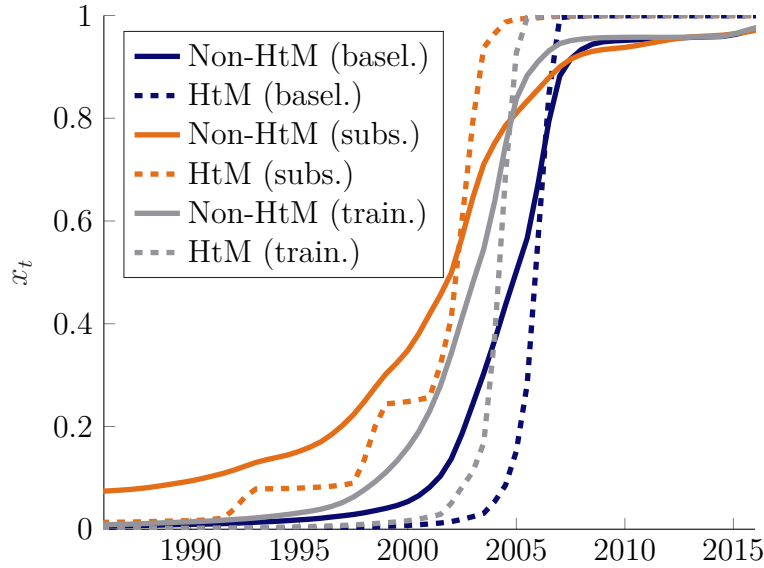


Figure 37: Exit decision x_t of experienced routine workers with $s = \bar{s}_{\text{old}}$, averaged across wealth and productivity.

E Trade Adjustment Assistance (TAA) for workers

E.1 Overview

The TAA is a program administered by the US Department of Labor and has been active since 2002. It provides several types of help to workers who have been adversely affected by foreign trade, e.g. training, Trade Readjustment Allowances (TRA) that provide income support while on training, relocation allowances, etc.⁵²

The TAA program that is closest in spirit to the transfer proposed in Section 6 are the Re-employment TAA (RTAA) benefits. These benefits provide wage supplements for eligible re-employed workers, aged 50 and over, whose re-employment resulted in lower wages than those earned in their trade-affected employment. In the newest (2015) amendment of the program, these payments may total 50% of the difference between old and new wages of the worker, with a maximum of 10,000\$ paid over a period of up to two years.

In their annual reports the US Congress, the TAA documents earnings before and after workers participated in any of their programs (not exclusively RTAA). Table 8 shows the percentage change in earnings for different age groups, averaged over the years for which this data is available (2015-2019).

⁵²All information provided in this section stems from the program's website, accessed on Jan 28, 2021: <https://www.dol.gov/agencies/eta/tradeact/>.

Table 8: Earnings of TAA participants after participation in the program, relative to earnings before participation (averaged over 2015-2019)

Age	All	<30	30-39	40-49	50-59	60+
Change	85%	108%	97%	87%	78%	60%

E.2 Success stories (2010-2019)

In the following I list a few of the “Success Stories” that are highlighted on the TAA’s website. In the context of my model, these stories provide concrete examples of occupational switches from the routine to the manual and abstract occupations. The occupational transitions documented here arguably entailed the need to apply a very different set of skills in the new job, rendering earlier accumulated occupational human capital close to worthless.

Jennifer Honn After working as a **forklift operator** at an Indiana factory for 10 years, Jennifer Honn lost her job when her company moved operations overseas. She was certified for Trade Adjustment Assistance, and took advantage of the training provided through the program to further her training. Working closely with her case manager, Jennifer decided to attend a local community college to earn a degree in Business Administration. After she earned her degree, she was hired as a **Human Resources Administrator** at a local pharmacy. [...]

Brandon Collins In November 2013, Brandon lost his job as a **maintenance mechanic** in a company that he worked with for 13 years before it moved its plant overseas. Prior to becoming an adversely affected worker, Brandon held an associate’s degree in Mechanics and a certificate in Welding from Southeast Community College. Under the TAA Program, Brandon decided to enroll in the Nursing program at North Central Missouri College. The TAA Program provided Brandon the opportunity to pursue a completely different career, which he had been interested in for many years. Brandon, a single father raising a son on his own, received training under TAA to become more competitive in the job market. In July 2015, Brandon successfully completed his training and received a Certificate in Nursing. He is now using his newly acquired skills and is working at a hospital in Fairfax, Missouri as a **Licensed Practical Nurse**. [...]

Kathy Motley At the age of 50, after 25 years of service, Kathy Motley was laid off from her **production job** at an Oklahoma factory. After being certified as eligible for the Trade Adjustment Assistance (TAA) program, she worked with her case manager and decided to attend school at Gordon Cooper Technology Center to become an **Aircraft Mechanic**. Kathy excelled in Aviation training and was chosen as the Aviation Maintenance Technician of the Year for the 2009-2010 General Class, and was given a perfect attendance award.

Shortly after earning her degree, she was hired at a local Air Force Base. [...]

Juan Bustamante Juan Bustamante worked as a **machine operator** in California for over eleven years at a company that produced aluminum car rims. However, when a large nearby auto manufacturing plant shifted its operations out of the country, Mr. Bustamante and 300 of his colleagues lost their production jobs. Even through his financial and family obligations, he was able to pursue training through the TAA program at the Los Angeles Valley College Job Training Center, where he took remedial courses in English, Math, and Speech. He then qualified for and completed the Transportation **Metro Bus Operator** Bridge Training Program, after which time he was hired on through a paid internship, and then as a full-time employee with full benefits and career ladder opportunities.

Scott Black Scott came to a Michigan Works! American Job Center in April 2016 after the **automotive plant** he worked for closed in Michigan. He had worked at the plant for 22 years, starting just after high school. Scott knew that, if he had the opportunity to go back to school, he wanted to be in the information technology (IT) field. Through the TAA Program, Scott explored career options with his case manager, and chose to begin an Associate Degree program of Computer Network Engineering - a program with a variety of employment opportunities and a high expectation of growth and job openings. He started training in September 2016. Scott graduated in June 2018 and received not only an Associate Degree in Computer Networking but also a Certificate in Computer Repair, receiving high honors in both programs. A few months after graduation, Scott was reemployed and found a promising career in **IT**. [...]

Jose Martinez Despite limited education and work experience, Jose Martinez found employment performing **packing and assembly operations**. In his six years with his company, Jose was promoted to Forklift Operator in the warehouse department, but was eventually laid off due to a shift in work overseas. Being an adversely affected worker, in May 2013, Jose took advantage of TAA Program benefits and services at the ValleyWorks Career Center (VWCC), including a Career Center Seminar, and attended a meeting with the VWCC staff. [...] With continued TAA support, Jose was able to later enroll in a Heating, Ventilation, Air-Conditioning and Refrigeration (HVAC-R) occupational skills training program at a local vocational school. [...] Upon graduating, Jose had three job offers and accepted employment as a **Heating, Air Conditioning and Refrigeration Mechanic** in July 2015.

Jacqueline Elmy Jacqueline was laid off in January of 2010 from a Pennsylvania insulation production company after working there for 21 years. Throughout her time there, she performed **forklift operation, warehouse, and production work**. After she was laid

off, she decided to pursue training as a Certified Nurse Aid, which she did through the Dislocated Worker program. However, her long term goal was to become a **Licensed Practical Nurse** (LPN), which was paid for through the TAA program. Ms. Elmy began training at the Wilkes-Barre Career and Technical Center in March 2011 for LPN under the Trade Act 2009 and completed her course work in June 2012. She graduated with honors and received awards of excellence for perfect attendance and for professionalism in the clinical setting. Ms. Elmy secured seasonal employment on August 23, 2012 as an LPN working at an immunization clinic, and additional employment working for a health agency that educates and conducts health fairs for local businesses. [...]