Immiserizing Automation*

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Abstract

Early-career jobs often serve as stepping stones to more productive occupations later in life. Automating such jobs may thus disrupt skill accumulation. We study this possibility in an overlapping-generations economy with career ladders, where senior work requires prior junior experience. Our main result is that *so-so automation* of junior tasks is immiserizing: when automation is just productive enough to be adopted, further improvements reduce steady-state output. This occurs because automating junior tasks *backloads* labor income over the life cycle, reducing the attractiveness of experience-intensive careers and the future supply of experienced workers. Policies that prevent immiseration harm the initial cohort of senior workers who benefit from the automation of junior tasks. Consistent with our mechanism, U.S. Census data show that industries more exposed to junior-task automation subsequently experienced lower employment and wage bills.

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1 Introduction

Work performed early in one's career is valuable not only for what it produces, but also for what it teaches. By carrying out junior tasks, workers accumulate the experience required to perform more demanding, better-paid tasks later in their careers. Automation of junior tasks may thus disrupt workers' skill accumulation. In this paper, we study the implications of such technological disruption for the long-run output of the economy.

We consider an overlapping-generations economy in which workers face one key trade-off: whether to earn higher wages when young or to invest in their human capital and earn higher wages later in life. Specifically, they can supply labor to either of two sectors. In the "modern" sector, performing senior tasks requires prior experience in its junior tasks. In the "traditional" sector, no experience is required. Workers sort into sectors based on comparative advantage and are free to smooth consumption through financial markets.

Our main theoretical result is that *so-so automation of junior tasks is necessarily immiserizing*: whenever the automation technology is only just efficient enough to be adopted, making it marginally more productive lowers steady-state output. The logic follows three steps. First, we use the envelope theorem to show that the wage gain to senior workers from automation is exactly offset by the wage loss to junior workers. Thus, so-so automation does not increase the lifetime earnings of a modern-sector worker; it merely shifts earnings from early to late in the career. Second, because workers discount future income, this additional backloading makes the modern sector less attractive and induces some workers to switch to the traditional sector. Third, the workers who exit are more productive in the modern sector. Indeed, the modern sector must offer higher lifetime earnings to compensate workers for its more backloaded wage profile. As a result, the reallocation of workers away from the modern sector reduces aggregate output.

So-so automation immiserates despite perfectly competitive and frictionless labor and financial markets. The key reason is that workers care not only about how much they earn over their lifetimes, but also about when they earn it. Technological progress that shifts earnings from early to late in the career can therefore reduce the attractiveness of occupations that rely on experience accumulation. In our model, this force pushes workers away from the modern sector—the very sector in which technological progress occurs—and thereby lowers aggregate output.

The cohort of workers who are seniors when automation is adopted are the main beneficiaries of the technological change: they enjoy the higher senior wage induced by automation without having borne the lower junior wage. This observation has an important normative implication. Any policy intervention that prevents immiseration must necessarily make this cohort worse off, ruling out Pareto improvements. At the same time, welfare in the new stationary equilibrium is lower for all workers pursuing modern-sector careers and may even be lower for all workers in the economy.

We then show that the immiseration result is robust to a range of extensions. In particular, it survives relaxing assumptions regarding the production technology, preferences, experience accumulation, financial markets, and workers' life cycle. Perhaps surprisingly, financial frictions do not necessarily amplify the effects of automation. By affecting equilibrium interest rates and workers' ability to smooth consumption, they can either dampen or amplify the decline in output.

To generate empirical predictions, we develop a multi-sector extension of the model in which both junior and senior tasks can be automated. The two forms of automation have sharply different implications. Whereas automation of junior tasks backloads earnings and discourages entry into affected occupations, automation of senior tasks frontloads earnings and makes those occupations more attractive. The model therefore predicts that industries should be affected more negatively by the automation of junior tasks than by the automation of senior tasks.

We test this prediction using measures of exposure to robot and software automation constructed from U.S. Census data. We classify occupations within industries as junior or senior based on the age profile of their workers and use this classification to construct industry-level exposure to junior- and senior-task automation. Consistent with the model, exposure to senior-task automation is associated with increases in employment and wage bills, whereas exposure to junior-task automation is associated with declines in both.

Our analysis is also relevant within the context of recent advances in artificial intelligence and the recurring concern that AI may disproportionately automate tasks performed by relatively inexperienced workers. To the extent that such tasks serve as stepping stones to more advanced occupations, their automation may affect not only current production but also the accumulation of experience and human capital. Our theory highlights one potential consequence: by weakening career ladders, AI-driven automation may discourage entry into affected occupations and reduce the future supply of experienced workers.

Our paper relates to several strands of the literature on automation and technological change. It builds on task-based theories of automation, particularly Acemoglu and Autor (2011), Acemoglu and Restrepo (2018), and Acemoglu and Restrepo (2019), in which automation reallocates tasks between workers and machines and may displace labor even when it raises productivity. We introduce a dynamic role for tasks. Because performing junior tasks is a prerequisite for performing senior tasks later in life, automating junior tasks affects not only the allocation of current production but also the future supply of experienced workers.

Our paper also contributes to a literature studying how automation can undermine the processes that sustain future productive capacity (Sachs and Kotlikoff (2012); Sachs et al. (2015); Benzell et al. (2018); Acemoglu et al. (2026)). In these papers, automation weakens the accumulation of productive inputs such as physical capital, code, or knowledge. In our setting, the relevant accumulation margin is occupational human capital. Junior work is the apprenticeship technology through which workers acquire experience, so automating junior tasks reduces future productivity by discouraging entry into the pipeline that produces senior labor.

Our analysis further connects to recent work on apprenticeship, training, and automation (Garicano and Rayo (2025); Ide (2025); Afrouzi et al. (2026)). These papers also emphasize that junior work is an input into future expertise, but they formalize this channel in different ways. In Garicano and Rayo (2025) and Ide (2025), automation affects explicit expert–novice training relationships; in Afrouzi et al. (2026), it changes on-the-job learning and the timing of workers' transition into management. Our distinct margin is entry into a backloaded modern-sector career: automation discourages entry into the pipeline itself and thereby reduces the steady-state supply of experienced modern-sector workers.

Closest to our treatment of the interaction between automation and financial frictions is Beraja and Zorzi (2025), who show that worker-displacing automation can be inefficiently fast. In our framework, financial frictions play a different role: by shaping the attractiveness of a backloaded career path, they either amplify or dampen the immiserizing effects of automation.

The paper is organized as follows. Section 2 presents the baseline framework. Sections 3 and 4 characterize the equilibrium and develop our main positive and normative results. Section 5 considers various extensions to the model. Section 6 presents empirical evidence on the differential effects of junior- and senior-task automation.

2 The Model

We begin by describing our model, in which experience accumulation is central to the labor market, and technical change—through task automation—affects the returns to such experience.

2.1 Environment

Overlapping generations and preferences. Time is discrete and indexed by $t = 0, 1, 2....$ The economy is populated by overlapping generations of workers who live for two periods. Each generation has a unit mass, and the set of workers born at date t is denoted by I_t. A worker $i \in I_t$ has lifetime utility:

$$U_t^i = u(c_{t,t}^i) + \beta \cdot u(c_{t,t+1}^i), \tag{1}$$

where $c_{t,t'}^i \geq 0$ denotes the consumption of worker i from generation t at date t' and $\beta \in (0, 1)$ is the workers' discount factor. More generally, for any choice variable x, we let $x_{t,t'}^i$ denote the choice of worker $i \in I_t$ made at date t'. We assume workers' preferences can be represented by a CRRA utility function:[1]

$$u(c) = \frac{c^{1-\gamma} - 1}{1-\gamma}, \quad \gamma \geq 0.$$

Technology. Each worker is endowed with one unit of labor in each period of life. Labor can be supplied either to a *traditional* sector or to a *modern* sector.

Output in the *modern sector* is produced competitively according to:

$$y_t^M = (S_t)^\alpha \cdot (J_t + k_t)^{1-\alpha},$$

where $\alpha \in (0,1)$, $S_t \geq 0$ denotes labor input (in efficiency units) employed in "senior" tasks—i.e., those that require experience—and $J_t \geq 0$ denotes human labor input in the remaining, "junior" tasks. k_t indicates an automation input that the firm can use to substitute for human labor in producing junior tasks. We use the Cobb-Douglas production function primarily for ease of exposition. Later, we extend our results to a more general class of production functions.

We impose the following assumption to ensure that there is a premium to experience in the modern sector:

Assumption 1 $\alpha > \frac{1}{2}$.

The automation technology allows firms to convert $\chi \cdot k_t$ units of the consumption good at date t into k_t efficiency units of junior labor, where $\chi > 0$. Automation, therefore, acts as a perfect substitute for junior labor in production, effectively expanding the economy's supply of junior labor at a constant marginal cost χ. In the main analysis, we assume that the cost of automating senior tasks is prohibitive. This allows us to isolate a form of technical change that selectively expands the supply of junior labor, thereby tilting workers' earnings profiles by *backloading* rewards over the life cycle. We relax this assumption in Section B.5, where we contrast our results with the case where senior tasks are automated, which we show has markedly different implications.

[1] For $\gamma = 1$, we set $u(c) = \log(c)$. We generalize our main results to the broader class of increasing and weakly concave utility functions in Section 5.

Output in the *traditional* sector is produced competitively according to:

$$y_t^T = L_t,$$

where $L_t \geq 0$ denotes efficiency units of labor input in that sector.

Occupations, tasks, and comparative advantage. Workers are heterogeneous in their productivity in the modern sector. Each worker $i \in I_t$ draws ψ^i from a distribution $F(\cdot)$, with support $(0, \psi^{\max})$ and $\int_0^{\psi^{\max}} \psi dF(\psi) < \infty$, where ψ^{max} may be infinite. The productivity ψ scales up a worker's effective units of labor in the modern sector, generating a comparative advantage across workers.[2] We ensure that both the modern and the traditional sectors are active in equilibrium by making the following assumption:

Assumption 2 $\psi^{\max} > (1 + \beta) \cdot \beta^{-\alpha}$.

A key feature of the economy is that experience is accumulated through work in the modern sector and determines access to experience-intensive tasks later in life. In each period, worker $i \in I_t$ chooses an occupation:

$$o_{t,t'}^i \in \{J, S, T\},$$

where J and S denote work in the modern sector performing junior and senior tasks, respectively, while T denotes work in the traditional sector.

Let $e_{t,t'}^i \in \{0, 1\}$ denote whether worker $i \in I_t$ has accumulated modern-sector experience by date t'. Young workers enter the labor market without experience:

$$e_{t,t}^i = 0.$$

Experience is gained by working in junior tasks in the modern sector when young:

$$e_{t,t+1}^i = \mathbf{1}\{o_{t,t}^i = J\}.$$

[2]Productivity heterogeneity ensures a unique equilibrium in pure strategies. In particular, workers sort across sectors according to a cutoff rule, allowing us to avoid mixed strategies that would otherwise be required if all workers were ex ante identical.

Given occupation and experience, effective labor supply is:

$$\ell^i_{t,t'} = \begin{cases} \psi^i & \text{if } o^i_{t,t'} = J, \\ \psi^i \cdot e^i_{t,t'} & \text{if } o^i_{t,t'} = S, \\ 1 & \text{if } o^i_{t,t'} = T. \end{cases} \tag{2}$$

Thus, experience is sector-specific: only those who work in the modern sector when young as juniors can access experience-intensive (senior) jobs when old. This creates a life-cycle trade-off: working in the modern sector when young yields lower current returns but enables access to higher-paying senior tasks when old. Section 5 discusses an extension where we allow for young workers to be productive in senior tasks too.

Labor market. There is a perfectly competitive labor market. At date t, firms take as given the wages per efficiency unit of labor—denoted by w^T_t, w^S_t, and w^J_t in the traditional sector, senior tasks, and junior tasks, respectively—and demand labor to produce output. Wages thus equal the marginal product of labor:

$$w^o_t = \begin{cases} (1-\alpha) \cdot \left(\frac{J_t + k_t}{S_t}\right)^{-\alpha} & \text{if } o = J, \\ \alpha \cdot \left(\frac{J_t + k_t}{S_t}\right)^{1-\alpha} & \text{if } o = S, \\ 1 & \text{if } o = T. \end{cases} \tag{3}$$

Workers take these wages as given and choose where to supply their labor.

Financial market. There is also a perfectly competitive financial market in which workers trade claims to future consumption. We let R_t denote the gross interest rate between dates t and $t+1$, i.e., borrowing one unit of the consumption good at date t requires a repayment of R_t units at date $t+1$.

Worker's optimization problem. A worker $i \in I_t$ chooses occupations $\{o^i_{t,t}, o^i_{t,t+1}\}$ and borrows b^i_t (or saves, when negative) to maximize her lifetime utility subject to the budget constraints:

$$c_{t,t}^{i} \leq w_{t}^{o_{t,t}^{i}} \cdot \ell_{t,t}^{i} + b_{t}^{i}, \tag{4}$$

$$c_{t,t+1}^{i} \leq w_{t+1}^{o_{t,t+1}^{i}} \cdot \ell_{t,t+1}^{i} - R_{t} \cdot b_{t}^{i}, \tag{5}$$

where $\ell_{t,t}^{i}$ and $\ell_{t,t+1}^{i}$ are the worker i's effective units of labor defined in (2) and w_t^o is the wage per effective unit of labor in occupation $o \in \{J, S, T\}$ as defined in (3).

2.2 Equilibrium

Having defined the environment, we now define a competitive equilibrium.

Definition 1 (Competitive Equilibrium) *Given an initial mass of experienced old workers $\int_{i \in I_{-1}} e_{-1,0}^{i} di$, a competitive equilibrium consists of sequences of prices $\{w_t^J, w_t^S, w_t^T, R_t\}_t$ and allocations $\{c_{t,t}^i, c_{t,t+1}^i, o_{t,t}^i, o_{t,t+1}^i, b_t^i\}_{i,t}$ and $\{J_t, S_t, L_t, k_t\}_t$, such that:*

- *Given prices, workers maximize lifetime utility in (1) subject to (2), (4) and (5);*
- *Wages w_t^o for $o \in \{J, S, T\}$ equal the marginal product of labor as in (3);*
- *Labor and asset markets clear at every date:*

$$J_t = \int_{\{i \in I_t : o_{t,t}^i = J\}} \ell_{t,t}^i \, di + \int_{\{i \in I_{t-1} : o_{t-1,t}^i = J\}} \ell_{t-1,t}^i \, di, \tag{6}$$

$$S_t = \int_{\{i \in I_t : o_{t,t}^i = S\}} \ell_{t,t}^i \, di + \int_{\{i \in I_{t-1} : o_{t-1,t}^i = S\}} \ell_{t-1,t}^i \, di, \tag{7}$$

$$L_t = \int_{\{i \in I_t : o_{t,t}^i = T\}} \ell_{t,t}^i \, di + \int_{\{i \in I_{t-1} : o_{t-1,t}^i = T\}} \ell_{t-1,t}^i \, di, \tag{8}$$

$$0 = \int_{\{i \in I_t\}} b_t^i \, di. \tag{9}$$

In what follows, we focus primarily on the stationary equilibria (steady states) of the economy, as our main results concern the long-run effects of automation. We therefore begin by characterizing the economy's steady states and how they vary with the cost of automation. Section 4 subsequently studies the transition dynamics induced by technological change.

Definition 2 (Stationary Equilibrium) *A stationary equilibrium is a competitive equilibrium in which all prices and allocations are constant over time.*

We next establish that the economy admits a unique stationary equilibrium. We then characterize this equilibrium by showing how the cutoff occupational choice and the equilibrium interest rate are jointly determined.

Proposition 1 (Existence and Uniqueness) *There is a unique stationary equilibrium.*

In any steady state, the mass of juniors and seniors employed in the modern sector must be equal. Competitive factor pricing therefore implies that equilibrium wages are pinned down by technology:

$$w^J = \min\{\chi, 1-\alpha\} \qquad \text{and} \qquad w^S = \alpha \cdot \left(\frac{1-\alpha}{w^J}\right)^{\frac{1-\alpha}{\alpha}}. \tag{10}$$

When $\chi \geq 1-\alpha$, junior tasks are not automated, and junior workers receive a share $1-\alpha$ of output per efficiency unit of labor in the modern sector. By contrast, when $\chi < 1-\alpha$, firms automate part of the junior tasks, and junior wages are pinned down by the automation cost χ.

Given the equilibrium wages in (10), and the fact that $w^T = 1$, the steady state is characterized by two conditions that jointly determine the allocation of workers across sectors and the interest rate that clears the financial market.

First, the allocation of workers across sectors is determined by occupational sorting. For a given interest rate R, there exists a cutoff worker $\bar{\psi} \in (0, \psi^{\max})$ who is indifferent between entering the modern and traditional sectors:

$$\bar{\psi} \cdot \left(w^J + \frac{w^S}{R}\right) = 1 + \frac{1}{R}. \tag{11}$$

This condition equates the discounted lifetime labor income associated with the two sectors for the marginal worker. As the wage profile in the modern sector is more backloaded than in the traditional sector, i.e., $w^J < w^S$, condition (11) induces a positive relationship between R and $\bar{\psi}$, depicted by the upward-sloping

Labor Market curve in Figure 1. Intuitively, a higher interest rate makes the modern sector less attractive because its rewards are more tilted toward the future. Therefore, the marginal worker must have a stronger comparative advantage in the modern sector in order to remain indifferent between the two sectors.

Second, the interest rate R is determined by the supply of savings and the demand for credit in the financial market. In equilibrium, workers in the traditional sector are the savers, whereas workers in the modern sector are the borrowers. For a given cutoff worker $\bar{\psi}$, financial market clearing therefore requires that:

$$F(\bar{\psi}) \cdot \left[1 - \omega(R) \cdot \left(1 + \frac{1}{R}\right)\right] = \int_{\bar{\psi}}^{\infty} \psi \, dF(\psi) \cdot \left[\omega(R) \cdot \left(w^J + \frac{w^S}{R}\right) - w^J\right], \quad (12)$$

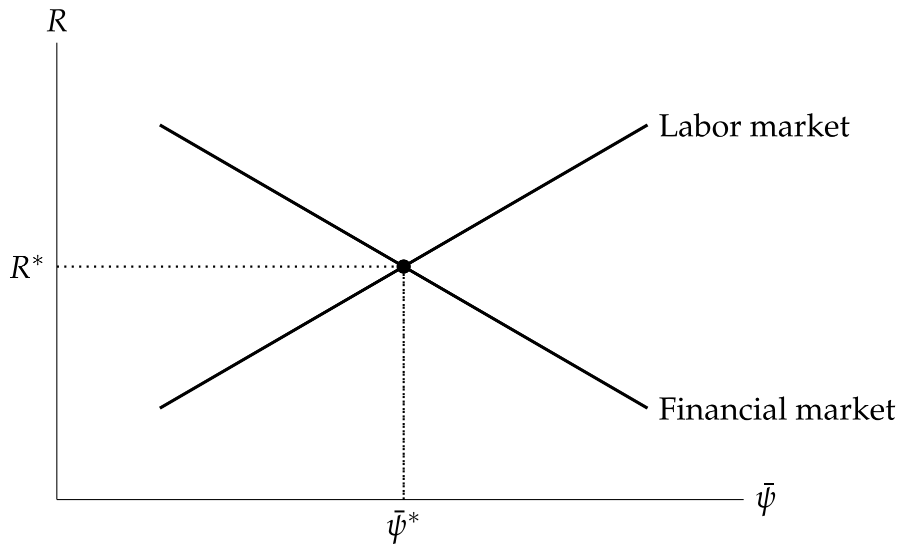
where $\omega(R) \equiv R/[R + (\beta \cdot R)^{\frac{1}{\gamma}}]$ denotes the share of discounted lifetime labor income that a worker consumes when young.[3] The left-hand side of (12) corresponds to aggregate savings by workers in the traditional sector, while the right-hand side corresponds to aggregate borrowing by workers in the modern sector. Condition (12) induces a negative relationship between R and $\bar{\psi}$, depicted by the downward-sloping Financial Market curve in Figure 1.[4] Intuitively, when more workers enter the modern sector, i.e., $\bar{\psi}$ decreases, the mass of borrowers relative to savers increases. Financial market clearing therefore requires a higher interest rate to incentivize more saving and less borrowing by workers.

The intersection of the two schedules pins down the equilibrium cutoff worker $\bar{\psi}^*$ and the interest rate R^*. Together, these objects fully characterize the unique stationary equilibrium. In the next section, we study how the equilibrium responds to changes in technology, first by characterizing comparative statics across stationary equilibria and then by analyzing the associated transitional dynamics. Before turning to this analysis, however, we establish that the steady state provides a natural point of departure: it is stable under the economy's equilibrium dynamics.

[3]For $\gamma = 0$, we have $\omega(R) = 1$ if $R < \beta^{-1}$, $\omega(R) = 0$ if $R > \beta^{-1}$, and $\omega(R) \in [0, 1]$ if $R = \beta^{-1}$.

[4]The relationship is downward sloping over the relevant range $\beta^{-1} \leq R \leq \beta^{-1} \cdot \left(w^S/w^J\right)^{\gamma}$. If $R < \beta^{-1}$, all workers would borrow, contradicting market clearing. Conversely, if $R > \beta^{-1} \cdot \left(w^S/w^J\right)^{\gamma}$, all workers would save, again contradicting market clearing.

Figure 1: Stationary Equilibrium Determination



Notes: R is the interest rate. $\bar{\psi}$ is the marginal worker's comparative advantage in the modern sector. Workers enter the modern sector iff $\psi \geq \bar{\psi}$ so a larger $\bar{\psi}$ implies a smaller modern sector.

Proposition 2 (Stability) *The stationary equilibrium is locally stable: for any initial mass of experienced workers in a neighborhood of* $1 - F(\bar{\psi}^*)$*, there is a unique path along which prices and allocations converge to their stationary-equilibrium values.*

We defer the discussion of the mechanisms underlying Proposition 2 to the next sections, where we first characterize how technological change affects the stationary equilibrium and then study the corresponding transition dynamics.

3 Immiseration

We now study how automation affects the stationary equilibrium of the economy. Our main result is that *so-so automation is always immiserizing*. We begin by defining so-so automation and immiseration formally.

Definition 3 (So-so Automation) *So-so automation is a marginal reduction in the automation cost* χ *at the adoption threshold* $\chi = 1 - \alpha$*.*

A reduction in χ to below $1-\alpha$ implies that automation inputs replace junior tasks previously performed by human workers. In this sense, it is automation.[5] However, when χ is only marginally below $1-\alpha$, automation is only marginally more cost-efficient than human labor. In this sense, the automation is "so-so."[6]

To define immiseration, we first provide a definition of output.

Definition 4 (Output) *Output is the economy's total production net of automation costs:*

$$Y_t = y_t^T + y_t^M - \chi \cdot k_t.$$

Because the economy cannot borrow or save in the aggregate, output equals aggregate consumption. Output is also equal to total wages earned by workers because constant returns to scale imply that firms make zero profits.

Immiseration is a reduction in output due to technical change.

Definition 5 (Immiseration) *Technical change is immiserizing if it reduces stationary-equilibrium output.*

The remainder of this section builds toward our main result that so-so automation is always immiserizing. The following lemma is the first step in that direction.

Lemma 1 (So-so Automation Rotates Wages) *So-so automation rotates wages while leaving their sum unchanged:*

$$\left.\frac{dw^J}{d\chi}\right|_{\chi=(1-\alpha)^-} = 1 \quad \text{and} \quad \left.\frac{dw^S}{d\chi}\right|_{\chi=(1-\alpha)^-} = -1.$$

This result follows from profit maximization and competitive factor pricing. A modern-sector firm's problem is:

$$\pi^M(\chi) = \max_{S,J,k} \left\{ y^M(S, J+k) - \chi \cdot k - w^S \cdot S - w^J \cdot J \right\}.$$

[5] While we do not explicitly model automation as an expansion in the set of tasks that can be feasibly performed with the automation input as is common in the literature (e.g., Acemoglu and Restrepo, 2018), our analysis is equivalent to studying how the effects of such technological change hitting junior tasks depend on how productive the automation technology is.

[6] We adopt the term "so-so automation" from (Acemoglu and Restrepo, 2019).

When automation inputs are used in the stationary equilibrium, the envelope theorem implies that:

$$\frac{\partial \pi^M}{\partial \chi} = -k - \frac{\partial w^J}{\partial \chi} \cdot J - \frac{\partial w^S}{\partial \chi} \cdot S.$$

Competition implies that profits are zero, so that:

$$\frac{\partial \pi^M}{\partial \chi} = 0.$$

Hence, at the adoption threshold where $k \approx 0$, the wage gain of the seniors must equal the wage loss of the juniors:

$$S \cdot \left.\frac{\partial w^S}{\partial \chi}\right|_{\chi=(1-\alpha)^-} = -J \cdot \left.\frac{\partial w^J}{\partial \chi}\right|_{\chi=(1-\alpha)^-}.$$

At the same time, when automation is adopted, junior wages are $w^J = \chi$ and thus $\frac{\partial w^J}{\partial \chi}|_{\chi=(1-\alpha)^-} = 1$. Since the stationary equilibrium has $S = J$, it follows that $\frac{\partial w^S}{\partial \chi}|_{\chi=(1-\alpha)^-} = -1$. Thus, as automation becomes viable, it rotates wages by lowering junior wages and raising senior wages one-for-one.

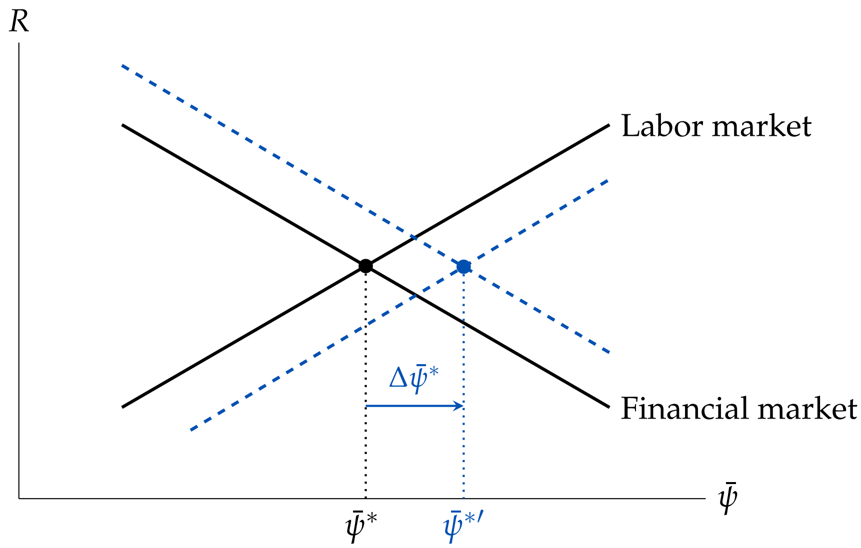
By backloading earnings in the modern sector, so-so automation reduces employment in that sector.

Lemma 2 (So-so Automation Shrinks the Modern Sector) *So-so automation reduces employment in the modern sector:*

$$\left.\frac{d\bar{\psi}^*}{d\chi}\right|_{\chi=(1-\alpha)^-} < 0.$$

The intuition is illustrated in Figure 2. Lemma 1 shows that so-so automation rotates wages in the modern sector by lowering earnings when young and raising earnings when old, without affecting average earnings. Since workers value earlier earnings relatively more than later earnings, this reallocation of earnings over the life cycle makes the modern sector less attractive. As a result, for a given interest rate, the marginal worker must have a stronger comparative advantage in the modern sector, shifting the Labor Market curve to the right. At the same time, the greater backloading of earnings increases borrowing demand by modern-sector

Figure 2: So-So Automation Shrinks the Modern Sector



Notes: R is the interest rate. $\bar{\psi}$ is the marginal worker's comparative advantage in the modern sector. Workers enter the modern sector iff $\psi \geq \bar{\psi}$ so a larger $\bar{\psi}$ implies a smaller modern sector.

workers, shifting the Financial Market curve to the right. Both forces push workers away from the modern sector, toward the traditional sector.

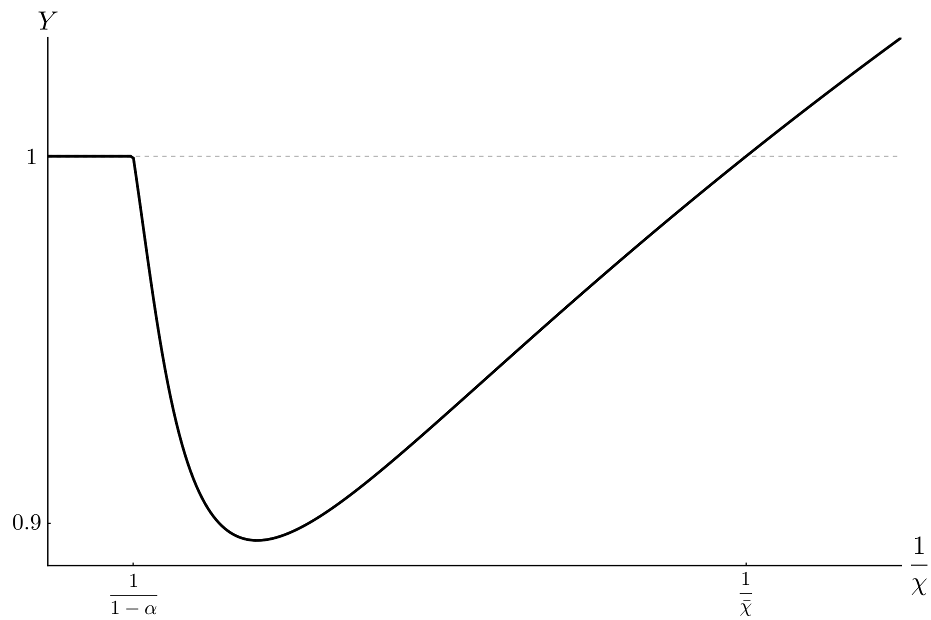
Finally, the shrinkage of the modern sector must reduce output. To see why, note that the backloaded wages in the modern sector must be compensated for by a higher average wage for a worker to be indifferent between the two sectors. Formally, from the labor market indifference condition (11), the interest rate being above one, and the positive experience premium, $w^S > w^J$, it follows that:

$$\bar{\psi}^* \cdot \left(w^J + w^S\right) > 2.$$

The marginal worker $\bar{\psi}^*$ thus sees a reduction in their average wages as so-so automation pushes them into the traditional sector. Instead, average wages of the inframarginal workers are not affected (by Lemma 1). Therefore, with fewer workers in the modern sector, total wages decline. Since a worker's average wage equals her contribution to the stationary-equilibrium output, output decreases too.

The proposition below formalizes this argument and states our main result.

Figure 3: So-So Automation Immiserizes



Notes: This figure depicts output relative to its pre-automation level as a function of automation efficiency $1/\chi$. Worker ability ψ is log-normal with mean $E[\psi] = 3$ and variance $Var[\psi] = 1/2$. The remaining parameters are $\alpha = 2/3$, $\beta = 4/5$, and $\gamma = 2$.

Proposition 3 (So-so Automation Immiserizes) *So-so automation is always immiserizing. In particular, there exists a* $\underline{\chi} < 1 - \alpha$ *such that stationary-equilibrium output is strictly lower when the cost of automation satisfies* $\chi \in (\underline{\chi}, 1 - \alpha)$ *than when* $\chi \geq 1 - \alpha$.

We note that the technical change considered here strictly expands the economy's production possibility frontier: the pre-automation allocation remains technologically feasible after automation becomes available. Immiseration arises because workers choose occupations based on the discounted present value of earnings rather than their average wage. By backloading earnings in the modern sector, so-so automation distorts occupational choice away from the sector where the technological progress occurs.

Figure 3 illustrates the process of immiseration that occurs as automation becomes efficient enough to be adopted. As long as $\chi > 1 - \alpha$, automation is not used in equilibrium, so local changes in its efficiency have no effect on output. Once χ

falls just below $1 - \alpha$, however, further reductions reduce output by Proposition 3. The economy therefore enters an immiseration region in which technological progress lowers output, eventually reaching a trough. As automation becomes sufficiently productive, however, the direct productivity gains dominate the distortionary effect on occupational choice, and output begins to rise with further improvements in automation technology.

Proposition 4 (Great Automation Drives Growth) *Sufficiently productive automation always increases output. In particular, there exists a $\bar{\chi} < 1 - \alpha$ such that stationary-equilibrium output is strictly higher when $\chi < \bar{\chi}$ than when $\chi \geq 1 - \alpha$.*

The immiserizing nature of so-so automation extends well beyond the specific assumptions adopted here for tractability. In particular, the arguments underlying Proposition 3 do not rely on the Cobb–Douglas production function, CRRA preferences, or the assumption that workers live for only two periods. Rather, the key ingredient is that automation disproportionately substitutes for tasks performed early in the life cycle and therefore backloads labor income in the modern sector. In Section 5, we discuss generalizations and extensions in detail.

The immiseration result is qualitatively different from the predictions in the now standard task-based models that so-so automation reduces wages (Acemoglu and Restrepo, 2018, 2019). In those models, even so-so automation always increases output. Whether wages decrease depends on how strongly automation reduces the labor share (the "displacement effect") relative to how much the overall size of the pie increases (the "productivity effect"). In contrast, Proposition 3 implies that in the economy studied here so-so automation reduces the overall size of the pie.

4 Transitions and Welfare Consequences

We now study the transition following the adoption of so-so automation. Suppose the economy is initially in a stationary equilibrium without automation and that, at date $t = 0$, the automation cost *unexpectedly* falls marginally below the adoption threshold $1 - \alpha$. Throughout, we focus on the locally stable equilibrium dynamics characterized in Proposition 2. Along this path, the cutoff worker $\bar{\psi}_t^*$, the interest rate R_t^*, wages, and occupational choices jump immediately to their new stationary-equilibrium values. The only state variable that cannot adjust on impact is the stock of experienced workers, which is determined by occupational choices made before automation was adopted.

Proposition 5 (Transition Dynamics) *Along the locally stable equilibrium path after so-so automation:*

1. *The cutoff worker $\bar{\psi}_t^*$, the interest rate R_t^*, and wages immediately jump to their new stationary-equilibrium values.*

2. *Output initially exceeds its new stationary-equilibrium level.*

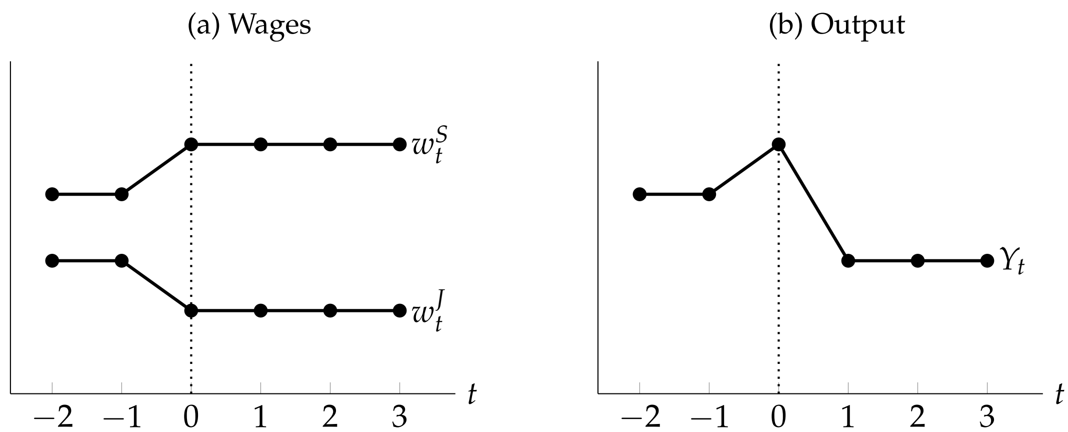
3. *The initial cohort of experienced workers strictly benefits from automation.*

Figure 4 illustrates these dynamics. Figure 4a shows that junior and senior wages immediately jump to their new stationary-equilibrium levels. Figure 4b shows that output follows a different path. While prices and occupational choices adjust on impact, the stock of experienced workers is predetermined. Consequently, the economy initially inherits the larger stock of senior workers accumulated before automation was adopted. Since automation increases the productivity of junior tasks while the supply of senior workers remains temporarily unchanged, output initially exceeds its new stationary-equilibrium level.

The initial rise in output may suggest that automation is benign. But the temporary boom reflects the stock of experienced workers accumulated under the pre-automation allocation. Once occupational choices adjust and the inherited stock of human capital is depleted, output falls to a lower steady-state level. In this sense, the immiserizing effects of automation are not immediately visible in aggregate output. So-so automation leaves existing experience intact but reduces workers' incentives to acquire experience, decreasing the future supply of senior labor.

The transition also creates winners. The initial cohort of senior workers in the modern sector benefits as it receives the higher senior wage induced by automation

Figure 4: Wages and Output During the Transition



Notes: t indexes time, with so-so automation adopted at $t = 0$.

without having borne the lower junior wage earlier in life. Thus, although so-so automation reduces stationary-equilibrium output, it strictly benefits this cohort.

We now turn to welfare of workers in the new stationary equilibrium.

Proposition 6 (Welfare Effects) *So-so automation reduces stationary-equilibrium welfare for all modern-sector workers and possibly for all workers.*

All modern-sector workers are made worse off because so-so automation backloads their wages. While a decrease in the interest rate can dampen their welfare loss, it cannot overturn the cost of backloading. The fact that the marginal worker moves to the traditional sector reflects this welfare loss.

The effect on traditional-sector workers' welfare is ambiguous. Being savers, these workers are also worse off if the interest rate falls. If the interest rate rises, they are better off. Both situations can occur in equilibrium.

Propositions 5 and 6 together imply that policies to prevent immiseration cannot avoid distributional conflict. Although so-so automation reduces stationary-equilibrium output and the welfare of at least some, if not all, future workers, it also creates a cohort of transition winners: the senior workers employed in the modern sector when automation is adopted. These workers receive the higher senior wage induced by automation without having borne the lower junior wage earlier in life. Any intervention that eliminates the immiserizing consequences of automation must therefore reduce the welfare of the initial transition winners or redistribute resources away from some other group of workers.

5 Extensions and Robustness

We consider several extensions of the baseline environment, including more general preferences and production technologies, the presence of financial frictions, and longer-lived households. We show that our main result, that so-so automation of junior tasks is immiserizing, is robust to these alternative specifications and generalizations. Below, we discuss each extension briefly, and we relegate more detailed analysis to Appendix B.

General Preferences and Technologies. The immiseration result does not depend on the Cobb–Douglas and CRRA specifications used in the baseline model. On the production side, it is sufficient for the technology to exhibit constant returns to scale, complementarity between junior and senior tasks, and a positive experience premium. Under these conditions, automation continues to rotate earnings toward later stages of the career. On the preference side, the result requires only that utility be increasing and weakly concave. Weak concavity implies that shifting income from youth to old age weakly increases workers' desired borrowing and therefore raises the attractiveness threshold for entering the modern sector. Consequently, both the Labor Market and Financial Market schedules shift in the same direction as in Figure 2, reducing modern-sector employment and output. CRRA preferences are useful primarily for ensuring uniqueness of the stationary equilibrium rather than for generating immiseration.

Immiseration Under Financial Frictions. The baseline model assumes that workers can freely borrow against future labor income. Because modern-sector careers feature a strongly backloaded wage profile, one might expect borrowing constraints to amplify the immiserizing effects of automation. We show that this intuition is incomplete. We introduce limited pledgeability of future labor income in the spirit of Hart and Moore (1994). Tighter borrowing constraints reduce the attractiveness of modern-sector careers and discourage experience accumulation. However, they also reduce aggregate borrowing demand and lower equilibrium interest rates. Since modern-sector workers are net borrowers, the resulting decline in interest rates partially offsets the occupational distortion. Consequently, financial frictions affect immiseration through two opposing channels. While so-so automation remains immiserizing, financial frictions may either attenuate or amplify the decline in output relative to the frictionless benchmark.

Beyond Two-Period Careers. The baseline model adopts a stark life-cycle structure in which workers spend one period as juniors and one period as seniors. We show that the immiseration result obtains in a perpetual-youth economy à la Yaari (1965) and Blanchard (1985), where workers face uncertain lifetimes and accumulate experience over the course of their careers. Although the environment is substantially richer, the equilibrium remains governed by the interaction of a Labor Market and a Financial Market schedule, as in Figure 2. So so automation continues to backload labor income by reducing the return to early-career work relative to later-career work. Consequently, entry into modern careers declines, the modern sector contracts, and aggregate output falls, just as in the baseline economy.

Alternative Paths to Senior Occupations. The baseline model assumes that experience acquired in junior jobs is the only route into senior careers. We relax this by allowing inexperienced workers to enter senior occupations directly, though at lower productivity than workers who first accumulate experience through apprenticeship. This alternative path does not eliminate immiseration. Direct entry is attractive because it flattens the life-cycle wage profile: relative to apprenticeship, it shifts income toward youth and reduces borrowing demand. As a result, once automation makes direct entry attractive, the economy passes through an intermediate regime in which apprenticeship and direct entry coexist: the interest rate is pinned by indifference between the two modern paths, and the share of workers entering through apprenticeship clears the financial market. In this region, workers substitute away from experience accumulation even though apprenticeship remains more productive, so direct entry can amplify the output decline before sufficiently cheap automation eventually raises production.

Junior- vs Senior-Task Automation. Our baseline model isolates the automation of junior tasks to highlight its effects on experience accumulation. Automation of senior tasks has the opposite implications. By raising the rewards to entering a modern-sector career relative to its later rewards, senior-task automation frontloads labor income and increases the attractiveness of occupations that rely on experience accumulation. As a result, workers reallocate toward the modern sector, expanding employment and raising aggregate output. This contrast between junior- and senior-task automation motivates the empirical analysis in Section 6.

6 Empirical Evidence

In this section, we provide evidence in support of our main theoretical mechanism: we find that sectors where junior tasks were disproportionally exposed to automation by robots saw a larger decrease in employment. Our theory predicts that automation concentrated in junior tasks is more harmful to a sector, i.e., lowers its employment, than automation of senior tasks. The key distinction between the two types of automation is that the former backloads wages toward later stages of a career, whereas the latter frontloads them, thereby discouraging and encouraging employment in the sector, respectively.

6.1 Data and Empirical Specification

We use micro-data from the US Census and the American Community Survey for each decadal year from 1970 to 2020. These data provide, for a representative sample of workers, their industry, occupation, age, and wage. We conduct the analysis at the level of the 1990 Census industry classification, which is consistently available across all years. For each industry and year we construct total employment, the total wage bill, and the average worker's age.

We use measures of an occupation's exposure to robots and software from (Webb, 2019). These measures are based on the overlap between the text of job task descriptions and the text of robotics and software patents. We refer to (Webb, 2019) for details regarding its construction.

Using these measures of occupational exposure, we first construct a measure of each *industry*'s overall exposure as the average occupation-level exposure of each person working this industry. That is,

$$\text{Automation}_s \equiv \frac{1}{n_s} \sum_{i:s^i_{80}=s} \text{OccAutomation}_{o^i_{t_0}} \tag{13}$$

where s indicates indexes the industry (or sector), s^i_{80} is the 1990 Census industry group that worker i is active in 1980, $n_s \equiv \sum_{i:s^i_{80}=s}$ is the sum of workers in sector s, OccAutomation_o is occupation o's exposure to automation, and o^i_{80} is worker i's occupation in the 1980 Census.[7]

We then construct measures of the degree to which an industry's automation exposure is concentrated in the more junior tasks. Our baseline measure of the junior-bias of automation is the negative of the correlation between a worker's age and their exposure. That is, for sector s,

$$\text{JuniorBias}_s = -\text{Corr}\left(\text{OccAutomation}_{o^i_{80}}, \text{Age}^i_{80} \mid s^i_{80} = s\right) \tag{14}$$

where Age^i_{80} is the age of the worker in the 1980 Census. Being a correlation, this measure is bounded between -1 and 1. If it is one, it means that there is a perfect negative correlation between age and exposure within the industry, so that the exposure is strongly biased to juniors. An advantage of this measure is that it captures how automation is distributed across tasks separately from how much automation the industry faces overall. However, we show that the results are robust to an alternative measure of junior bias. Specifically, we also show results measuring junior bias as the difference between the exposure of workers who are younger vs. older than the industry-specific median age. We use the industry-

[7]We use the 1990 occupational classification system, which is consistently available in the census data.

specific median age to ensure that both measures are computed based on equally-sized population.

We estimate the following difference-in-difference specification:

$$\log y_{st} = \sum_{t' \neq 1980} \mathbf{1}\{t' = t\} \left(\beta_{t'} \cdot \text{JuniorBias}_s + \gamma_{t'} \cdot \text{Automation}_s\right) + \mu_s + \lambda_t + \varepsilon_{st}, \tag{15}$$

where y_{st} is the outcome of interest for industry s in year t and μ_s and λ_t are industry- and year fixed effects, respectively. Both the junior bias and the measure of overall automation exposure are fixed at their 1980 values and interacted with year indicators, with 1980 as the omitted base year.

The coefficients of interest are the $\beta_{t'}$, which reflect how the outcome of an industry is correlated with the degree to which its automatable tasks are junior tasks, holding total exposure fixed. The model predicts that automating junior tasks depresses sector employment relative to automating senior tasks, so that we expect these parameters to be negative.

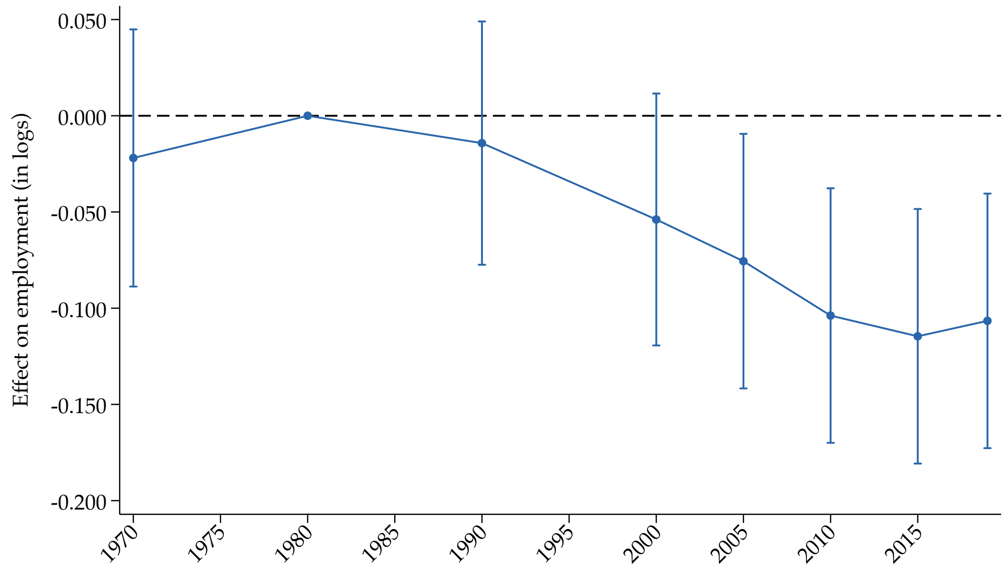
6.2 Results

Consistent with the theory, we find that exposure to robots has had a more negative effect on industry-level employment when it was biased to junior tasks. Figure 5 reports the estimates of the regression in equation (15) with log employment as the dependent variable. While junior bias does not correlate with changes in employment before 1990, it is correlated with a substantial decline after. Quantitatively, the effects suggest that an industry for which the junior bias was one standard deviation stronger saw an additional decline of about 10% in employment.

We find very similar results when considering the effects of software: junior bias in automation predicts subsequent declines in employment, while not showing signs of pre-trends (see Figure C.3).

The result that employment decreases more with junior than with senior automation is robust to various alternative model specifications. First, it is robust to using the difference between junior and senior exposure as independent variable

Figure 5: Employment Effects of Junior Bias in Robot Exposure



Notes: This figure reports estimates of the parameters $\beta_{t'}$ in equation (15). The dependent variable is an industry's log employment. The coefficients are normalized by the standard deviation of the independent variable so that they reflect effects per standard deviation of junior bias. The regression controls for year- and industry- fixed effects and for the overall exposure of the industry to automation by robots, interacted by year. The bars reflect 90% confidence intervals.

as opposed to the correlation between age and exposure (Figure C.4). Second, it is robust to measuring exposure using 1990 as the baseline instead of 1980 as in Acemoglu and Restrepo (2020) (Figure C.5). Lastly, we replicate the exercise when constructing robot exposure measures based on the binary replaceability measure by Graetz and Michaels (2018). The binary nature of this measure increases noise, but the effect size and direction are similar (Figure C.6).

Further, we find that junior-biased automation predicts an increase in the average age of workers in the industry. To show this, we use the same specification as in equation (15), except for changing the dependent variable to the log average age in the industry. Figures C.7a and C.7b show positive effects of junior bias on the industry-level average age for robots and software, respectively. These results are consistent with our model's prediction along the transition path where junior entry is lower than the existing stock of seniors.

7 Conclusion

This paper studies how automation affects the incentives to accumulate experience. In our model, workers acquire skills by performing junior tasks and are compensated with a backloaded earnings profile. Automating junior tasks reduces the value of the first step of the career ladder, making experience accumulation less attractive and inducing workers to reallocate away from experience-intensive occupations. As a result, the future supply of experienced workers declines. When automation is initially modest, these reallocation effects can dominate its direct productivity gains, causing aggregate output and welfare to fall. We show that this mechanism is robust to a variety of extensions, including financial frictions, longer life cycles, and alternative career paths. We also provide empirical evidence consistent with the model's central prediction: industries more exposed to automation of junior tasks experience slower employment growth and lower output growth than industries exposed to automation of senior tasks. More broadly, our results suggest that the long-run effects of automation depend not only on the tasks it replaces today, but also on how it reshapes the incentives to accumulate the experience and skills that future production requires.

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Appendix

A Proofs and Derivations for Sections 2-4

Proof of Proposition 1. Since both the Labor Market and Financial Market schedules, given by (11) and (12), define continuous maps from $\bar{\psi}$ to R, to establish existence and uniqueness, it is sufficient to show that one of them is downward sloping in $(\bar{\psi}, R)$-space while the other is upward sloping.

The labor market condition (11) implies

$$R = \frac{\bar{\psi} w^S - 1}{1 - w^J \bar{\psi}}$$

which yields an upward sloping curve in $(R, \bar{\psi})$ since $\bar{\psi} w^S > 1$ and $w^J \bar{\psi} < 1$.

The financial market condition (12) implies

$$\frac{(\beta R)^{\frac{1}{\gamma}} - 1}{w^S - (\beta R)^{\frac{1}{\gamma}} w^J} = \frac{\int_{\bar{\psi}}^{\infty} \psi \, dF(\psi)}{F(\bar{\psi})}.$$

Since the left-hand side of this equation is increasing in R, while the right-hand side is decreasing in $\bar{\psi}$, equation (12) induces a negative relationship between R and $\bar{\psi}$. This establishes uniqueness.

To prove existence, note that for $\bar{\psi} = \frac{1}{w^S}$, $R = 0$ and there must be strictly more demand for borrowing than supply of saving. Also, when $\bar{\psi} \to \frac{1}{w^J}$, $R \to \infty$ and there must be excess supply of savings. Since both equations are continuous, existence follows from the intermediate value theorem. ■

Proof of Proposition 2. We establish the result separately for the case with and without automation.

Case without automation: $\chi > 1 - \alpha$**.** The dynamic equivalent of the financial market conditions implies

$$\mathcal{F}\left(\bar{\psi}_{t-1},\bar{\psi}_t,\bar{\psi}_{t+1}\right)=\left(\left(\beta R_t\right)^{\frac{1}{\gamma}}-1\right)F\left(\bar{\psi}_t\right)-\left(w^S_{t+1}-\left(\beta R_t\right)^{\frac{1}{\gamma}}w^J_t\right)\int_{\bar{\psi}_t}^{\infty}\psi\,dF(\psi)=0.$$

where prices w^J_t, w^S_{t+1} and R_t are functions of $\bar{\psi}_{t-1}$, $\bar{\psi}_t$, $\bar{\psi}_{t+1}$ only. The dynamics of the economy can therefore be characterized by the second-order difference equation in $\bar{\psi}_{t-1}$, $\bar{\psi}_t$, and $\bar{\psi}_{t+1}$.

We establish local stability by analyzing the stability of the first-order approximation to the nonlinear dynamic system:

$$\left.\frac{\partial\mathcal{F}}{\partial\bar{\psi}_{t-1}}\right|_*\left(\bar{\psi}_{t-1}-\bar{\psi}^*\right)+\left.\frac{\partial\mathcal{F}}{\partial\bar{\psi}_t}\right|_*\left(\bar{\psi}_t-\bar{\psi}^*\right)+\left.\frac{\partial\mathcal{F}}{\partial\bar{\psi}_{t+1}}\right|_*\left(\bar{\psi}_{t+1}-\bar{\psi}^*\right)=0.$$

where $\cdot|_*$ indicates the derivative is evaluated at the steady state.

Some algebra yields

$$\begin{aligned}
\left.\frac{\partial\mathcal{F}}{\partial\bar{\psi}_{t+1}}\right|_* &= \frac{\beta}{\gamma}\left(\beta R^*\right)^{\frac{1}{\gamma}-1}\frac{\partial R_t}{\partial\bar{\psi}_{t+1}}\left(F\left(\bar{\psi}^*\right)+w^J\int_{\bar{\psi}^*}^{\infty}\psi\,dF(\psi)\right)-\frac{\partial w^S_{t+1}}{\partial\bar{\psi}_{t+1}}\int_{\bar{\psi}^*}^{\infty}\psi dF(\psi)\\
\left.\frac{\partial\mathcal{F}}{\partial\bar{\psi}_t}\right|_* &= \frac{\beta}{\gamma}\left(\beta R^*\right)^{\frac{1}{\gamma}-1}\frac{\partial R_t}{\partial\bar{\psi}_t}\left(F(\bar{\psi}^*)+w^J\int_{\bar{\psi}^*}^{\infty}\psi\,dF(\psi)\right)\\
&\quad+f(\bar{\psi}^*)\left[\left(\beta R^*\right)^{\frac{1}{\gamma}}-1\right]-\frac{\partial w^S_{t+1}}{\partial\bar{\psi}_t}\int_{\bar{\psi}^*}^{\infty}\psi\,dF(\psi)\\
&\quad+\left(\beta R^*\right)^{\frac{1}{\gamma}}\frac{\partial w^J_t}{\partial\bar{\psi}_t}\int_{\bar{\psi}^*}^{\infty}\psi\,dF(\psi)+\left(w^S-\left(\beta R^*\right)^{\frac{1}{\gamma}}w^J\right)\bar{\psi}^*f(\bar{\psi}^*)\\
\left.\frac{\partial\mathcal{F}}{\partial\bar{\psi}_{t-1}}\right|_* &= \frac{\beta}{\gamma}\left(\beta R^*\right)^{\frac{1}{\gamma}-1}\frac{\partial R_t}{\partial\bar{\psi}_{t-1}}\left(F(\bar{\psi}^*)+w^J\int_{\bar{\psi}^*}^{\infty}\psi\,dF(\psi)\right)+\left(\beta R^*\right)^{\frac{1}{\gamma}}\frac{\partial w^J_t}{\partial\bar{\psi}_{t-1}}\int_{\bar{\psi}^*}^{\infty}\psi\,dF(\psi).
\end{aligned}$$

For stability of the linearized system, we require one eigenvalue to be within the unit circle and the other outside the unit circle. In other words, we require the characteristic polynomial

$$H(\lambda)=\left.\frac{\partial\mathcal{F}}{\partial\bar{\psi}_{t+1}}\right|_*\cdot\lambda^2+\left.\frac{\partial\mathcal{F}}{\partial\bar{\psi}_t}\right|_*\cdot\lambda+\left.\frac{\partial\mathcal{F}}{\partial\bar{\psi}_{t-1}}\right|_*$$

to have exactly one root between -1 and 1.

To show that the linearized system is locally stable, it is sufficient that $H(1)$ and $H(-1)$ are of opposite sign. To see why, note that the opposite signs of $H(1)$ and $H(-1)$ impliy that $H(\lambda)$ has an odd number of roots within $(-1,1)$. Since $H(\lambda)$ is quadratic it has at most two roots and thus exactly one root within $(-1,1)$.

We use that

$$
\begin{aligned}
\left.\frac{\partial R_t}{\partial \bar{\psi}_{t+1}}\right|_* &= \frac{\bar{\psi}^* \frac{\partial w^S_{t+1}}{\partial \bar{\psi}_{t+1}}|_*}{1 - w^J \bar{\psi}^*} \\
\frac{\partial R_t}{\partial \bar{\psi}_t}|_* &= \frac{w^S + R^* w^J + \bar{\psi}^* \frac{\partial w^S_{t+1}}{\partial \bar{\psi}_t}|_* + R^* \bar{\psi}^* \frac{\partial w^J_t}{\partial \bar{\psi}_t}|_*}{1 - w^J \bar{\psi}^*} \\
\frac{\partial R_t}{\partial \bar{\psi}_{t-1}}|_* &= \frac{R^* \bar{\psi}^* \frac{\partial w^J_t}{\partial \bar{\psi}_{t-1}}|_*}{1 - w^J \bar{\psi}^*} \\
\left.\frac{\partial w^S_{t+1}}{\partial \bar{\psi}_{t+1}}\right|_* &= -\left.\frac{\partial w^S_{t+1}}{\partial \bar{\psi}_t}\right|_* = -(1-\alpha) w^S \frac{\bar{\psi}^* f(\bar{\psi}^*)}{\int_{\bar{\psi}^*}^{\infty} \psi \, dF(\psi)}, \\
\left.\frac{\partial w^J_t}{\partial \bar{\psi}_t}\right|_* &= -\left.\frac{\partial w^J_t}{\partial \bar{\psi}_{t-1}}\right|_* = \alpha w^J \frac{\bar{\psi}^* f(\bar{\psi}^*)}{\int_{\bar{\psi}^*}^{\infty} \psi \, dF(\psi)}.
\end{aligned}
$$

From there,

$$
\begin{aligned}
H(1) =& \left.\frac{\partial \mathcal{F}}{\partial \bar{\psi}_{t+1}}\right|_* + \left.\frac{\partial \mathcal{F}}{\partial \bar{\psi}_t}\right|_* + \left.\frac{\partial \mathcal{F}}{\partial \bar{\psi}_{t-1}}\right|_* \\
=& \frac{\beta}{\gamma} (\beta R^*)^{\frac{1}{\gamma}-1} \left(F(\bar{\psi}^*) + w^J \int_{\bar{\psi}^*}^{\infty} \psi \, dF(\psi) \right) \left(\left.\frac{\partial R_t}{\partial \bar{\psi}_{t+1}}\right|_* + \left.\frac{\partial R_t}{\partial \bar{\psi}_t}\right|_* + \left.\frac{\partial R_t}{\partial \bar{\psi}_{t-1}}\right|_* \right) \\
& + f(\bar{\psi}^*) \left((\beta R^*)^{\frac{1}{\gamma}} - 1 \right) + \left(w^S - (\beta R^*)^{\frac{1}{\gamma}} w^J \right) \bar{\psi}^* f(\bar{\psi}^*)
\end{aligned}
$$

so that

$$H(1) > 0$$

because

$$\left.\frac{\partial R_t}{\partial \bar{\psi}_{t+1}}\right|_* + \left.\frac{\partial R_t}{\partial \bar{\psi}_t}\right|_* + \left.\frac{\partial R_t}{\partial \bar{\psi}_{t-1}}\right|_* = \frac{w^S + R^* w^J}{1 - w^J \bar{\psi}^*} > 0$$

and

$$1 \leq (\beta R^*)^{\frac{1}{\gamma}} \leq \frac{w^S}{w^J}.$$

It remains to prove that $H(-1) < 0$. Again, combining terms, we obtain

$$\begin{aligned}
H(-1) &= \left.\frac{\partial \mathcal{F}}{\partial \bar{\psi}_{t+1}}\right|_* - \left.\frac{\partial \mathcal{F}}{\partial \bar{\psi}_t}\right|_* + \left.\frac{\partial \mathcal{F}}{\partial \bar{\psi}_{t-1}}\right|_* \\
&= \frac{\beta}{\gamma}\left(\beta R^*\right)^{\frac{1}{\gamma}-1}\left(F\left(\bar{\psi}^*\right) + w^J \int_{\bar{\psi}^*}^{\infty} \psi \, dF(\psi)\right)\left(\left.\frac{\partial R_t}{\partial \bar{\psi}_{t+1}}\right|_* - \left.\frac{\partial R_t}{\partial \bar{\psi}_t}\right|_* + \left.\frac{\partial R_t}{\partial \bar{\psi}_{t-1}}\right|_*\right) \\
&\quad - f\left(\bar{\psi}^*\right)\left(\left(\beta R^*\right)^{\frac{1}{\gamma}} - 1\right) - \left(w^S - \left(\beta R^*\right)^{\frac{1}{\gamma}} w^J\right)\bar{\psi}^* f\left(\bar{\psi}^*\right) \\
&\quad - 2\left(\left(\beta R^*\right)^{\frac{1}{\gamma}} - 1\right)\alpha(1-\alpha)\bar{\psi}^* f\left(\bar{\psi}^*\right)
\end{aligned}$$

so that

$$H(-1) < 0$$

because

$$\left.\frac{\partial R_t}{\partial \bar{\psi}_{t+1}}\right|_* - \left.\frac{\partial R_t}{\partial \bar{\psi}_t}\right|_* + \left.\frac{\partial R_t}{\partial \bar{\psi}_{t-1}}\right|_* = -\frac{w^S + R^* w^J + 2\bar{\psi}^* \frac{\partial w^S_{t+1}}{\partial \bar{\psi}_t} + 2R^* \bar{\psi}^* \frac{\partial w^J_t}{\partial \bar{\psi}_t}}{1 - w^J \bar{\psi}^*} < 0$$

and

$$1 \leq \left(\beta R^*\right)^{\frac{1}{\gamma}} \leq \frac{w^S}{w^J}.$$

The linearized system thus has exactly one eigenvalue within the unit circle. Since the model has one predetermined variable and one forward-looking variable, this linearized system is locally stable. That is, there exists a locally unique path toward the stationary equilibrium. By the Hartman-Grobman theorem, this implies that the non-linear system is locally stable too.

Case with automation: $\chi < 1 - \alpha$. With automation, wages are pinned down by χ in a neighborhood around the steady state. This implies that wages do not respond locally to changes in entry thresholds and thus

$$\begin{aligned}
\left.\frac{\partial R_t}{\partial \bar{\psi}_{t+1}}\right|_* &= 0 \\
\frac{\partial R_t}{\partial \bar{\psi}_t}|_* &= \frac{w^S + R^* w^J}{1 - w^J \bar{\psi}^*} \\
\frac{\partial R_t}{\partial \bar{\psi}_{t-1}}|_* &= 0.
\end{aligned}$$

The result then follows from the same reasoning as above because it implies that $H(1) > 0$ and $H(-1) < 0$. ■

Proof of Lemma 1. See text. ■

Proof of Lemma 2. See text. ■

Proof of Proposition 3. See text for the proof that the stationary-equilibrium output must be strictly increasing in χ near the automation threshold $\chi = (1-\alpha)^-$. By continuity of output in χ, this implies that there exists a $\underline{\chi} < 1-\alpha$ such that output is strictly lower when the cost of automation satisfies $\chi \in (\underline{\chi}, 1-\alpha)$ than when $\chi > 1-\alpha$. ■

Proof of Proposition 4. It is sufficient to show that stationary-equilibrium output goes to infinity as $\chi \to 0$. When $\chi < 1-\alpha$, senior wages (per efficiency unit of labor) are:

$$w^S = \alpha \cdot \left(\frac{1-\alpha}{\chi}\right)^{\frac{1-\alpha}{\alpha}} \to \infty \text{ as } \chi \to 0.$$

Since output equals total wages, it is sufficient to show that the senior wage bill must go to infinity, i.e., that:

$$w^S \cdot \int_{\bar{\psi}}^{\psi^{\max}} \psi \, dF(\psi) \to \infty.$$

If $\bar{\psi}$ remains bounded away from $\psi^{\max}$, the result is immediate since $w^S \to \infty$. Thus, suppose instead that $\bar{\psi} \to \psi^{\max}$ so that $\int_{\bar{\psi}}^{\psi^{\max}} \psi \, dF(\psi) \to 0$ and $F(\bar{\psi}) \to 1$.

From the Labor Market condition (11), if employment in the modern sector goes to zero, i.e., $\bar{\psi} \to \psi^{\max}$, while senior wages tend to infinity, i.e., $w^S \to \infty$, the interest rate must tend to infinity too, i.e., $R \to \infty$. The Financial Market condition (12) implies that:

$$\frac{\int_{\bar{\psi}}^{\psi^{\max}} \psi \, dF(\psi)}{F(\bar{\psi})} = \frac{1 - \omega(R) \cdot \left(1 + \frac{1}{R}\right)}{\omega(R) \cdot \left(w^J + \frac{w^S}{R}\right) - w^J}.$$

Since denominator is no greater than $\omega(R) \cdot w^S / R$, we obtain:

$$\frac{w^S \cdot \int_{\bar{\psi}}^{\psi^{\max}} \psi \, dF(\psi)}{F(\bar{\psi})} \geq R \cdot \left(\frac{1}{\omega(R)} - 1 - \frac{1}{R} \right) = (\beta \cdot R)^{1/\gamma} - 1, \tag{16}$$

where we used the expression for $\omega(R)$ defined by Equation (12).[8] Since $R \to \infty$, the right-hand side of (16) goes to ∞ too. Since $F(\bar{\psi}) \to 1$:

$$w^S \cdot \int_{\bar{\psi}}^{\psi^{\max}} \psi \, dF(\psi) \to \infty.$$

Hence, total wages and output must tend to infinity as $\chi \to 0$, which in turn implies that output is higher with automation than without it whenever $\chi \in (0, \bar{\chi})$ for $\bar{\chi}$ small enough. ■

Proof of Proposition 5. From Proposition 2, there exists a unique locally stable equilibrium path converging from the pre-automation steady state to the post-automation steady state. The text constructs an equilibrium in which both the cutoff $\bar{\psi}_t^\star$ and the interest rate $R_t^\star$ jump immediately to their post-automation steady-state values following the adoption of automation. Since this equilibrium converges to the post-automation steady state, uniqueness implies that it coincides with the locally stable path.

Workers who are already senior in the transition period receive the higher senior wage induced by automation without having experienced the lower junior wage earlier in life. Their lifetime income therefore increases, implying that they strictly benefit from so-so automation.

Finally, output rises on impact. The cutoff rises immediately, so some workers who would have entered the modern sector as junior workers instead work in the traditional sector. The marginal worker at the pre-automation cutoff satisfies:

$$\bar{\psi}^* \cdot \left(w^J + \frac{w^S}{R^*} \right) = 1 + \frac{1}{R^*}.$$

[8] The expression for $\omega(R)$ is only valid for $\gamma > 0$. But note that for $\gamma = 0$ (linear preferences), the result is immediate since it implies that $R = \frac{1}{\beta}$ so that modern-sector employment can not go to zero as $w^S \to \infty$.

Since $w^S > 1$ and $R^* > 1$, it follows that

$$\bar{\psi}^* \cdot w^J < 1.$$

Hence the marginal worker produces less than one unit of output as a junior worker in the modern sector but exactly one unit in the traditional sector. The induced reallocation therefore raises output on impact. ■

Proof of Proposition 6. We first show that modern-sector workers must be worse-off after so-so automation. Let $U^M(\psi, w^J, w^S, R)$ be the lifetime utility of a worker with productivity ψ in the modern sector when junior and senior wages are w^J and w^S, respectively, and the interest rate is R.

Since CRRA preferences imply that consumption scales linearly with lifetime income (and thus with ψ). This implies that modern-sector utility increases for all ψ if and only if it increases for any ψ.

Suppose towards contradiction that $\tilde{U}^M(w^J, w^S, R)$ increases after so-so automation. Since the marginal worker moves to the traditional sector (Lemma 2), traditional-sector utility $U^T(R)$ must increase too (by revealed preference). Since traditional-sector utility is increasing in R by the envelope theorem, this implies that R increases. However, when R increases, and the senior wage increases by as much as the junior wage decreases, the discounted value of the modern-sector career decreases, and thus utility $\tilde{U}^M(w^J, w^S, R)$ must decrease, a contradiction. ■

B Details on Extensions

In this section, we consider several extensions of the baseline environment, including more general preferences and production functions, financial constraints, and longer-lived households. We show that our main result, that so-so automation of junior tasks is immiserizing, is robust to these alternative specifications and generalizations. We also discuss some additional insights that these extensions provide.

B.1 General Production Functions and Preferences

Production functions. The Cobb-Douglas assumption is not necessary for immiseration to occur. It is sufficient that the aggregate production function exhibits constant returns to scale, complementarity between junior and senior tasks, and a positive experience premium.

Let modern output be produced according to a constant-returns-to-scale production function $Y^M(S, J+k)$. Under constant returns to scale, wages depend only on the effective junior-senior task ratio $(J+k)/S$. In a stationary equilibrium without automation, $k=0$, this task ratio is one. Once automation is efficient enough to be used in steady state, the marginal cost of automation pins down the marginal product of junior tasks:

$$w^J = Y_2^M\left(1, \left(\frac{J+k}{S}\right)\right) = \chi$$

where Y_2^M is the derivative of $Y^M(\cdot,\cdot)$ with respect to junior task input. The automation cost χ thus determines the task ratio and junior and senior wages. The experience premium is positive absent automation if $Y_1^M(1,1) > Y_2^M(1,1)$.

Any CRS production function implies that so-so automation increases the senior wage by as much as it decreases the junior wage. This follows directly from the same envelope argument used to prove Lemma 1, which does not rely on the Cobb-Douglas form, only on constant returns to scale and competitive factor pricing.

From there, the mechanism illustrated in Figure 2 carries over. So-so automation backloads wages in the modern sector, shifting both curves to the right, reducing modern-sector entry and output.

Note that aggregate constant returns to scale are consistent with decreasing returns to scale on the firm level, as long as there is free entry that drives profits to zero. Thus immiseration by so-so automation carries over to such settings too. Absent free entry, automation may generate rents, and the welfare and output effects depend on how those rents are allocated.

Preferences. Immiseration by so-so automation does not depend on CRRA utility. It holds for any increasing and weakly concave utility function.

Preferences affect the stationary equilibrium only through workers' saving and borrowing decisions and thus shape the Financial Market curve in Figure 1. For a general utility function $u(\cdot)$, the Financial Market equation in (12) becomes:

$$-F(\bar{\psi}) \cdot b\,(R, 1, 1) = \int_{\bar{\psi}}^{\infty} b\left(R, \psi \cdot w^J, \psi \cdot w^S\right)\, dF(\psi),$$

where $b(R, w_1, w_2)$ denotes the demand for borrowing when the interest rate is R and the income when young and old are w_1 and w_2, respectively:

$$b(R, w_1, w_2) = \arg\max_b \left\{u(w_1 + b) + \beta \cdot u(w_2 - R \cdot b)\right\}.$$

Weak concavity of $u(\cdot)$ is enough to ensure that borrowing demand increases when income is shifted from youth to old age.[9] Since so-so automation generates exactly such shift, it increases borrowing demand for any given interest rate R. Financial market clearing then requires a smaller mass of borrowers and a higher cutoff $\bar{\psi}$, shifting the Financial Market curve to the right. Since the shape of the Labor Market is not affected by preferences, both equilibrium schedules shift to the right, as in Figure 2, and so-so automation increases $\bar{\psi}^*$ and reduces output.[10]

The immiseration result thus only requires a weakly concave utility function. CRRA is useful to ensure that the stationary equilibrium is unique, for which a concave utility function is not sufficient.

[9] That is, a weakly concave utility function implies that for any $0 < w_1 < w_2$, $R > 0$, and $\Delta > 0$,

$$b\,(R, w_1 - \Delta, w_2 + \Delta) \geq b\,(R, w_1, w_2)\,.$$

[10] When the utility function is linear (as nested by CRRA), the Financial Market curve is horizontal and the rightward shift of the Labor Market curve is sufficient to generate immiseration.

B.2 Financial Frictions

Our baseline model assumes that workers can freely borrow and lend against future labor income. This assumption is particularly relevant because the modern sector features a strongly backloaded wage profile: workers earn a low junior wage before receiving a substantially higher senior wage. A natural conjecture is therefore that financial frictions amplify the immiserizing effects of automation by making a modern-sector career less attractive. We show, however, that this intuition is incomplete. Although so-so automation continues to generate immiseration under financial frictions, the magnitude of the effect is no longer straightforward. Financial frictions affect both occupational choice and equilibrium interest rates, giving rise to opposing forces that shape the severity of immiseration.

To capture these effects, we consider a simple extension with limited pledgeability of labor income in the spirit of Hart and Moore (1994). We assume that workers can walk away from their financial obligations and retain a fraction $1-\theta$ of their senior earnings. Consequently, creditors can recover at most a fraction θ of old-age income, implying the borrowing constraint:

$$R_t \cdot b_t^i \leq \theta \cdot \psi^i \cdot w^S.$$

The parameter $\theta \in [0,1]$ captures the degree of financial development. When $\theta = 1$, future labor income is fully pledgeable and the economy coincides with our baseline specification. Lower values of θ tighten borrowing constraints by reducing the fraction of future earnings that can be pledged to investors.

The introduction of financial frictions leaves the structure of the equilibrium characterization largely unchanged. There are, however, two important modifications relative to the baseline model. First, the analogue of the indifference condition (11) between the modern and the traditional sector must now account for the possibility that workers in the modern sector are financially constrained. The occupational cutoff is thus determined by equality of lifetime utility rather than of discounted lifetime income. The resulting Labor Market condition becomes:

$$\bar{\psi} = \left[\frac{c^T(R)^{1-\gamma} + \beta \cdot \left[1 + R - R \cdot c^T(R)\right]^{1-\gamma}}{c^M(R)^{1-\gamma} + \beta \cdot [w^S + R \cdot w^J - R \cdot c^M(R)]^{1-\gamma}} \right]^{\frac{1}{1-\gamma}}, \tag{17}$$

where:

$$c^T(R) \equiv \omega(R) \cdot \left(1 + \frac{1}{R}\right); \; c^M(R) \equiv \min\left\{ \omega(R) \cdot \left(w^J + \frac{w^S}{R}\right), w^J + \frac{\theta \cdot w^S}{R} \right\}.$$

Here, $c^T(R)$ and $c^M(R)$ are the consumption levels (per efficiency unit of labor) of traditional- and modern-sector workers, and $\omega(R)$ is the share of lifetime income consumed if constraints were slack. When constraints bind, young modern-sector workers consume less than in the baseline model, as limited pledgeability prevents them from fully smoothing consumption over the life cycle. As in the baseline model, this condition defines a downward-sloping relationship between $\bar{\psi}$ and R.

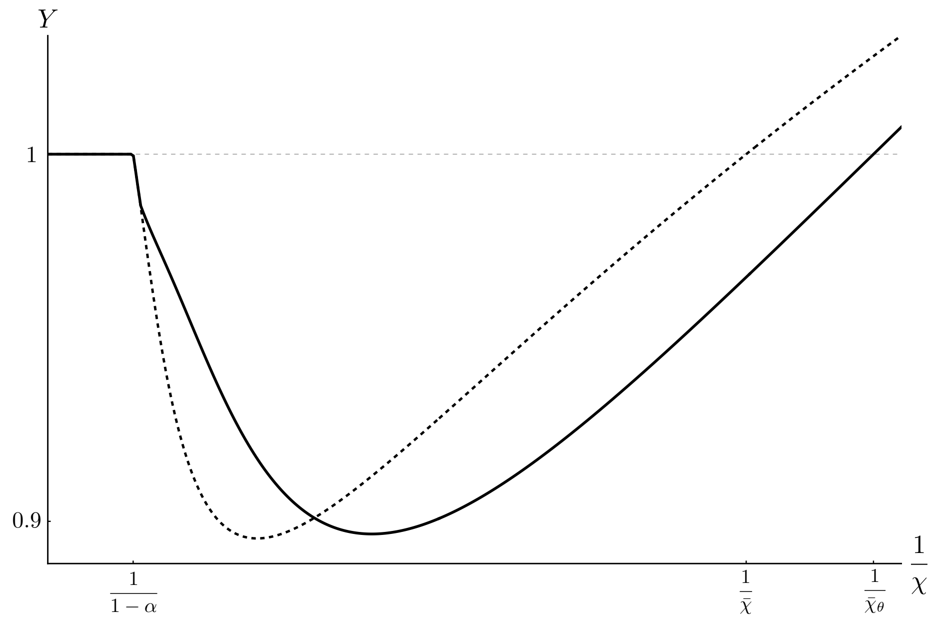
Second, the analog of the financial market clearing condition (12), which defines the Financial Market curve, is now given by:

$$F(\bar{\psi}) \cdot \left[1 - c^T(R)\right] = \int_{\bar{\psi}}^{\infty} \psi \, dF(\psi) \cdot \left[c^M(R) - w^J\right]. \tag{18}$$

Whereas the savings function $1 - c^T(R)$ of the traditional-sector workers is as before, the borrowing function $c^M(R) - w^J$ is now depressed due to limited pledgeability. Nevertheless, as in the baseline model, this condition yields an upward-sloping relationship between $\bar{\psi}$ and R.

The unique stationary equilibrium is given by the intersection of the Labor Market and Financial Market schedules. The two conditions make transparent how financial frictions affect immiseration. Through the Labor Market condition (17), tighter borrowing constraints reduce the utility value of a modern-sector career because workers cannot fully transfer resources from their high-earning senior years to their low-earning junior years. Holding interest rates fixed, this lowers entry into the modern sector and amplifies the decline in experience acquisition. Through the Financial Market condition (18), tighter borrowing constraints

Figure B.1: Immiseration Under Financial Frictions



Notes: This figure depicts output relative to its pre-automation level as a function of automation efficiency $1/\chi$ with financial frictions ($\theta = 1/8$, solid line) and without ($\theta = 1$, dashed line). Both economies are governed by the same preference and technological parameters as the economy depicted in Figure 3.

reduce borrowing demand and therefore lower the equilibrium interest rate. Since modern-sector workers are net borrowers while traditional-sector workers are net lenders, the resulting decline in interest rates improves the intertemporal terms of trade faced by the former and offsets the occupational-choice distortion.

Financial frictions therefore affect immiseration through a tension between an occupational-choice distortion and a terms-of-trade effect. Despite this ambiguity, the qualitative effect of automation remains unchanged: a decline in the automation cost shifts both the Labor Market and Financial Market schedules to the right (as in Figure 2), raising the occupational cutoff, reducing modern-sector employment, and lowering stationary-equilibrium output.

Figure B.1 illustrates these forces. The dashed curve corresponds to our baseline economy, while the solid curve corresponds to an economy in which borrowing constraints begin to bind only after the economy enters the immiseration region. Initially, financial frictions attenuate immiseration because the equilibrium-interest-rate effect dominates. As the cost of automation becomes lower, however, the occupational-choice distortion becomes increasingly important and eventually dominates. Consequently, financial frictions first mitigate and later amplify the decline in output relative to the frictionless benchmark.

B.3 Beyond Two-Period Lifetimes

In this section, we consider an extension of our baseline model in the spirit of Blanchard (1985) and Yaari (1965), in which workers live for a random number of periods and accumulate experience gradually over the course of their careers. This allows us to show that our main results do not rely on the stylized two-period lifetime structure of the baseline model. In particular, workers in the modern sector now make consumption and financial decisions throughout both their junior and senior careers, rather than borrowing when young and repaying when old.

Specifically, suppose that workers survive from one period to the next with a probability $\zeta \in (0,1)$. A mass $1-\zeta$ of newborn workers enters each period, so the population remains constant. Workers who enter the modern sector begin their careers as inexperienced juniors and, conditional on remaining alive, become experienced senior workers with a probability $\lambda \in (0,1)$ each period. Once a worker becomes senior, she remains senior until death.

As in our baseline setup, financial markets are frictionless. In addition to borrowing and saving freely at the market interest rate R, workers can fully insure against both mortality and experience-accumulation risk.[11] As a result, individual consumption and portfolio choices depend only on expected lifetime labor income. We focus on the stationary equilibrium of this economy and summarize its key implications here, relegating the full characterization to Section B.3.1. The structure of the equilibrium remains similar to that in the baseline economy.

Let $W^J(R,\chi)$ denote the expected discounted labor income of a worker who enters the modern sector as a junior worker, and let $W^T(R)$ denote the corresponding object for a traditional-sector worker. Unlike in the traditional sector, lifetime labor

[11] Such insurance can be implemented through annuities and state-contingent borrowing against future labor income.

income in the modern sector depends on the automation cost χ, which affects both junior and senior wages. Occupational choice is characterized by:

$$\bar{\psi} \cdot W^J(R, \chi) = W^T(R). \tag{19}$$

As in the baseline model, this condition defines a Labor Market schedule relating the occupational cutoff $\bar{\psi}$ and the interest rate R. Workers enter the modern sector if and only if their productivity exceeds the cutoff $\bar{\psi}$.

The equilibrium interest rate is determined by a market clearing condition that equates the savings of traditional-sector workers with the borrowing demand of workers in the modern sector:

$$F(\bar{\psi}) \cdot S^T(R) = \int_{\bar{\psi}}^{\infty} \psi \, dF(\psi) \cdot B^M(R, \chi), \tag{20}$$

where $S^T(R)$ denotes savings per traditional-sector worker and $B^M(R, \chi)$ denotes borrowing per efficiency unit of labor supplied to the modern sector. As in the baseline model, this condition defines a Financial Market schedule. For a given occupational cutoff, the interest rate equates aggregate savings and borrowing.

The intersection of the Labor Market and Financial Market schedules, defined by (19) and (20), determines the stationary equilibrium pair $(\bar{\psi}^*, R^*)$, which in turn fully characterizes the stationary equilibrium of the economy. In Section B.3.1, we show formally that our main result—namely, that so-so automation is immiserizing— continues to hold in this richer environment. The logic is essentially identical to that in the baseline model, and we briefly summarize it here.

As in the baseline economy, automation is adopted whenever its cost falls below a threshold $\widehat{\chi}$. We therefore study the effects of a marginal decline in χ below $\widehat{\chi}$. At the adoption threshold, automation affects only the composition of wages in the modern sector. In particular, for a given allocation of labor between juniors J and seniors S, it lowers the junior wage one-for-one while raising the senior wage so that the total wage bill per efficiency unit of labor remains unchanged:

$$\frac{dw^J}{d\chi}\Big|_{\chi=\widehat{\chi}^-} = 1, \qquad \frac{dw^S}{d\chi}\Big|_{\chi=\widehat{\chi}^-} = -\frac{J}{S}.$$

Thus, automation makes the modern-sector wage profile more backloaded, shifting labor income from earlier to later stages of the life cycle.

Because workers in the modern sector receive a backloaded stream of labor income and in equilibrium $R > 1$,[12] this wage rotation reduces the discounted lifetime labor income of a worker entering the modern sector as a junior:

$$\frac{\partial W^J(R,\chi)}{\partial \chi}\Big|_{\chi=\widehat{\chi}^-} > 0.$$

As in the baseline model, the resulting decline in lifetime labor income makes the modern-sector less attractive and shifts the Labor Market schedule to the right. At the same time, by transferring income towards later stages of the career, automation increases the borrowing demand of workers pursuing a modern-sector career:

$$\frac{\partial B^M(R,\chi)}{\partial \chi}\Big|_{\chi=\widehat{\chi}^-} < 0. \tag{21}$$

Hence, the Financial Market schedule also shifts to the right. Therefore, a marginal decline in χ below $\widehat{\chi}$ necessarily raises the equilibrium occupational cutoff $\bar{\psi}^*$.

Finally, a higher cutoff $\bar{\psi}^*$ reduces the supply of labor to the modern sector. Because the modern sector pays a premium for its backloaded wage profile, it is also the more productive at the margin. Consequently, reallocating workers away from the modern sector lowers aggregate output. The mechanism underlying immiseration is therefore not an artifact of the stylized two-period structure of the baseline model. Rather, it arises more generally whenever automation increases the backloading of labor income and thereby weakens incentives to acquire experience.

B.3.1 Additional Derivations

Workers survive from one period to the next with probability $1-\zeta$, and a mass ζ of newborn workers enters each period. Workers who enter the modern sector begin as juniors and, conditional on survival, become seniors with probability λ

[12] The interest rate exceeds one both due to discounting ($\beta < 1$) and because the average lifetime income in the economy is backloaded ($w^S > w^J$).

each period. Once senior, a worker remains senior until death.

Workers have preferences:

$$U_t = \sum_{s=t}^{\infty} \left[(1-\zeta)\cdot\beta\right]^{s-t} \cdot u(c_{t,s}),$$

where $c_{t,s}$ is the period-s consumption of a worker born at t, with CRRA period utility $u(c) = \frac{c^{1-\gamma}}{1-\gamma}$. Asset markets are complete, so workers can fully insure against mortality and experience-accumulation risk. Standard consumption-smoothing arguments imply that consumption is proportional to lifetime wealth, i.e., $c = \kappa(R)\cdot W$ where $\kappa(R) = 1 - q(R)\cdot(\beta R)^{1/\gamma}$ and $q(R) = \frac{1-\zeta}{R}$.

The stationary stocks of junior and senior workers per efficiency unit of labor supplied to the modern sector are:

$$J = \frac{\zeta}{1-(1-\zeta)\cdot(1-\lambda)}, \qquad S = \frac{(1-\zeta)\cdot\lambda}{\zeta}\cdot J,$$

so that:

$$\frac{S}{J} = \frac{(1-\zeta)\cdot\lambda}{\zeta}.$$

The lifetime labor incomes of modern-sector senior and junior workers are:

$$W^S(R) = \frac{w^S}{1-q(R)} \text{ and } W^J(R,\chi) = \frac{w^J + \frac{q(R)\cdot\lambda}{1-q(R)}\cdot w^S}{1-q(R)\cdot(1-\lambda)},$$

and the corresponding object for workers in the traditional sector is:

$$W^T(R) = \frac{1}{1-q(R)}.$$

Occupational choice is characterized by:

$$\bar{\psi}\cdot W^J(R,\chi) = W^T(R).$$

This equation defines the Labor Market schedule in (19). To derive the Financial

Market schedule, let:

$$\mathcal{W}^M(R,\chi) = J \cdot W^J(R,\chi) + S \cdot W^S(R)$$

denote lifetime labor-income wealth per efficiency unit supplied to the modern sector. Aggregate consumption is:

$$C(R,\bar{\psi}) = \kappa(R) \cdot \left[F(\bar{\psi}) \cdot W^T(R) + \int_{\bar{\psi}}^{\infty} \psi dF(\psi) \cdot \mathcal{W}^M(R,\chi) \right].$$

Aggregate output is:

$$Y(R,\bar{\psi}) = F(\bar{\psi}) + \int_{\bar{\psi}}^{\infty} \psi dF(\psi) \cdot Y^M,$$

where $Y^M = J \cdot w^J + S \cdot w^S$ is the output per efficiency worker in the modern sector. Market clearing, $C(R,\bar{\psi}) = Y(R,\bar{\psi})$, can therefore be written as:

$$F(\bar{\psi}) \cdot S^T(R) = \int_{\bar{\psi}}^{\infty} \psi dF(\psi) \cdot B^M(R,\chi),$$

where:

$$S^T(R) = 1 - \kappa(R) \cdot W^T(R) = 1 - \frac{\kappa(R)}{1 - q(R)}$$

is saving per traditional-sector worker and:

$$B^M(R,\chi) = \kappa(R) \cdot \mathcal{W}^M(R,\chi) - Y^M$$

is borrowing demand per efficiency unit supplied to the modern sector. This equation defines the Financial Market schedule in (20).

We now characterize the effect of so so automation. Modern-sector output per efficiency unit is:

$$Y^M = S^\alpha \cdot (J + k)^{1-\alpha}.$$

Since automation caps the junior wage at χ, we have:

$$w^J = \min \left\{ \chi, (1-\alpha) \cdot \left(\frac{S}{J} \right)^\alpha \right\}.$$

The automation-adoption threshold is therefore:

$$\widehat{\chi} = (1-\alpha) \cdot \left(\frac{S}{J}\right)^{\alpha} = (1-\alpha) \cdot \left(\frac{(1-\zeta) \cdot \lambda}{\zeta}\right)^{\alpha}.$$

At the adoption threshold:

$$\frac{dw^J}{d\chi} = 1.$$

Since $w^S = \alpha \cdot \left(\frac{1-\alpha}{w^J}\right)^{\frac{1-\alpha}{\alpha}}$, we have:

$$\frac{dw^S}{d\chi} = -\frac{J}{S}.$$

Thus,

$$dY^M = J \cdot dw^J + S \cdot dw^S = 0.$$

Differentiating $W^J(R, \chi)$ with respect to χ yields:

$$\frac{\partial W^J(R,\chi)}{\partial \chi} = \frac{1 - \frac{q(R)\cdot\lambda}{1-q(R)} \cdot \frac{J}{S}}{1 - q(R) \cdot (1-\lambda)} = \frac{\frac{R-1}{R-(1-\zeta)}}{1 - \frac{1-\zeta}{R} \cdot (1-\lambda)} > 0,$$

where the last inequality follows from the fact that $R > 1$ in any stationary equilibrium. Thus, a decline in χ lowers the lifetime labor income of a worker entering the modern sector as a junior and shifts the Labor Market schedule to the right.

Next, differentiating $\mathcal{W}^M(R, \chi)$ with respect to χ yields:

$$\frac{\partial \mathcal{W}^M(R,\chi)}{\partial \chi} = J \cdot \frac{q(R) \cdot (1-\lambda) - 1}{[1-q(R)] \cdot [1 - q(R) \cdot (1-\lambda)]} < 0.$$

Since $dY^M = 0$ at the automation threshold, we have:

$$\frac{\partial B^M(R,\chi)}{\partial \chi} = \kappa(R) \cdot \frac{\partial \mathcal{W}^M(R,\chi)}{\partial \chi} < 0.$$

Thus, a decline in χ raises borrowing demand per efficiency unit supplied to the modern sector and shifts the Financial Market schedule to the right.

Both equilibrium schedules therefore shift to the right after a marginal decline in χ below the automation threshold, thereby raising the equilibrium cutoff $\bar{\psi}^*$. Since marginal automation leaves output per efficiency unit supplied to the modern sector unchanged ($dY^M = 0$), the only first-order effect on aggregate output comes from the induced reallocation of workers across sectors. Because the modern sector must compensate workers for its backloaded wage profile, it is more productive than the traditional sector in equilibrium ($\bar{\psi}^* \cdot Y^M > 1$). The resulting increase in $\bar{\psi}^*$ reallocates workers away from the modern sector and lowers aggregate output. Thus, so-so automation is immiserizing.

B.4 Alternative Paths to Senior Occupations

Our baseline model assumes that workers must accumulate experience in junior tasks before performing senior tasks. Technological change–and, more recently, AI-based tools–may relax these experience requirements by allowing less experienced workers to perform tasks that previously required substantial experience. A natural interpretation is that junior workers can team up with AI systems to perform some senior tasks directly. Thus, workers may gain access to alternative paths into senior occupations.

To capture this possibility, suppose that a young worker can enter a senior occupation directly. A worker of type ψ who does so supplies $\kappa_1\psi$ efficiency units of senior labor when young and $\kappa_2\psi$ efficiency units when old, where

$$0 < \kappa_1 \leq \kappa_2 < 1.$$

The restriction $\kappa_2 < 1$ implies that workers who bypass apprenticeship never become as productive as workers who first accumulate experience in junior occupations. Experience accumulation therefore remains valuable from an output perspective, even though it is no longer technologically necessary to perform senior tasks.

Workers choose among three career paths:

$$D : (\psi\kappa_1 w^S, \psi\kappa_2 w^S), \qquad A : (\psi w^J, \psi w^S), \qquad T : (1, 1),$$

where D denotes direct entry into senior occupations, A denotes apprenticeship, and T denotes a traditional-sector career. Because financial markets are complete and preferences are CRRA, workers rank occupational paths by discounted lifetime labor income. Direct entry is weakly preferred to apprenticeship if and only if

$$\kappa_1 + \frac{\kappa_2}{R} \geq \frac{w^J}{w^S} + \frac{1}{R}. \tag{22}$$

We focus on the case in which this condition fails in the pre-automation equilibrium but is satisfied once automation sufficiently reduces the value of junior tasks. Direct entry is therefore inactive before automation is adopted but emerges as an alternative career path after automation becomes sufficiently advanced.

One might conjecture that allowing workers to enter senior occupations directly weakens the immiseration mechanism. After all, workers who would otherwise leave the modern sector may instead remain in it and perform senior tasks. This intuition is incomplete. Direct entry offers a flatter lifetime earnings profile than apprenticeship. At an apprenticeship–direct-entry tie, indifference implies

$$\kappa_1 w^S - w^J = \frac{(1-\kappa_2)w^S}{R} > 0.$$

Thus direct entry shifts income from old age to youth relative to apprenticeship. At a common discounted value, it also generates less borrowing demand. Since the comparison between the two modern paths is independent of ψ, any strict preference for one path sends all modern entrants to that path. Hence, when direct entry first becomes attractive at the apprenticeship-only allocation, an immediate switch of all modern entrants to direct entry generally cannot clear the financial market. In the intermediate region, the equilibrium instead keeps the two modern paths tied and clears the financial market by adjusting the fraction of modern entrants in apprenticeship.

The tie between apprenticeship and direct entry pins down the interest rate:

$$R_{AD} = \frac{1-\kappa_2}{\kappa_1 - \frac{w^J}{w^S}}.$$

At this interest rate, apprenticeship and direct entry share the same cutoff against traditional work:

$$\bar{\psi}_{AD} = \frac{1+1/R_{AD}}{w^J + w^S/R_{AD}} = \frac{1+1/R_{AD}}{\kappa_1 w^S + \kappa_2 w^S/R_{AD}}.$$

Let $m \in [0,1]$ denote the fraction of modern entrants assigned to apprenticeship. Financial market clearing in the mixed regime is

$$\begin{aligned} &F(\bar{\psi}_{AD})\left[1-\omega(R_{AD})\left(1+\frac{1}{R_{AD}}\right)\right] \\ &\quad = \int_{\bar{\psi}_{AD}}^{\infty} \psi\, dF(\psi)\left\{ m\left[\omega(R_{AD})\left(w^J + \frac{w^S}{R_{AD}}\right) - w^J\right] \right. \\ &\qquad\qquad \left. + (1-m)\left[\omega(R_{AD})\left(\kappa_1 w^S + \frac{\kappa_2 w^S}{R_{AD}}\right) - \kappa_1 w^S\right]\right\}. \end{aligned} \tag{23}$$

This equation determines the apprenticeship share m. The mixed regime is valid when the implied value of m lies in $[0,1]$. If the implied value exceeds one, the apprenticeship-only regime is the relevant candidate; if it is negative, the direct-only regime is the relevant candidate.

In the apprenticeship-only regime, condition (22) fails at the equilibrium interest rate and the baseline Labor Market and Financial Market conditions apply. In the direct-only regime, the cutoff against traditional work is

$$\bar{\psi}_D = \frac{1+1/R}{\kappa_1 w^S + \kappa_2 w^S/R}.$$

The interest rate is determined by

$$F(\bar{\psi}_D)\left[1-\omega(R)\left(1+\frac{1}{R}\right)\right] = \int_{\bar{\psi}_D}^{\infty}\psi\,dF(\psi)\left[\omega(R)\left(\kappa_1 w^S+\frac{\kappa_2 w^S}{R}\right)-\kappa_1 w^S\right], \tag{24}$$

together with the requirement that condition (22) holds at the resulting interest rate.

The hybrid path in which a worker starts in traditional work and enters senior tasks directly when old does not create an additional regime. Let $\bar{\psi}$ denote the cutoff between traditional work in both periods and modern work in both periods. At this cutoff, $\bar{\psi}\kappa_1 w^S \leq 1$; otherwise, since $\kappa_2 \geq \kappa_1$, direct entry in both periods would strictly dominate traditional work. For $\psi < \bar{\psi}$, the hybrid path has the same young income as traditional work and lower old income, so traditional work dominates it. For $\psi > \bar{\psi}$, scale the cutoff comparison by $\psi/\bar{\psi}$. Homotheticity implies that entering modern in both periods is at least as good as the scaled traditional profile, and this scaled profile dominates the hybrid path because its young income is above one and, by $\bar{\psi}\kappa_1 w^S \leq 1$, its old income is at least $\psi\kappa_1 w^S$. Thus the hybrid path is never chosen.

Production in the apprenticeship-only regime is

$$J_A = S_A = \int_{\bar{\psi}}^{\infty}\psi\,dF(\psi).$$

In the mixed regime,

$$J_{AD} = m\int_{\bar{\psi}_{AD}}^{\infty}\psi\,dF(\psi), \qquad S_{AD} = \left[m+(1-m)(\kappa_1+\kappa_2)\right]\int_{\bar{\psi}_{AD}}^{\infty}\psi\,dF(\psi).$$

In the direct-only regime,

$$J_D = 0, \qquad S_D = (\kappa_1+\kappa_2)\int_{\bar{\psi}_D}^{\infty}\psi\,dF(\psi).$$

Factor prices satisfy the usual competitive conditions:

$$w^J = (1-\alpha)\left(\frac{S}{J+k}\right)^{\alpha} \leq \chi, \qquad w^S = \alpha\left(\frac{J+k}{S}\right)^{1-\alpha},$$

with equality $w^J = \chi$ whenever automation is used. Since firms make zero profits after paying for automation, stationary net output equals total labor income. Thus, in the mixed regime,

$$Y_{AD} = 2F(\bar{\psi}_{AD}) + \int_{\bar{\psi}_{AD}}^{\infty} \psi \, dF(\psi) \left[m(w^J + w^S) + (1-m)(\kappa_1 + \kappa_2)w^S\right],$$

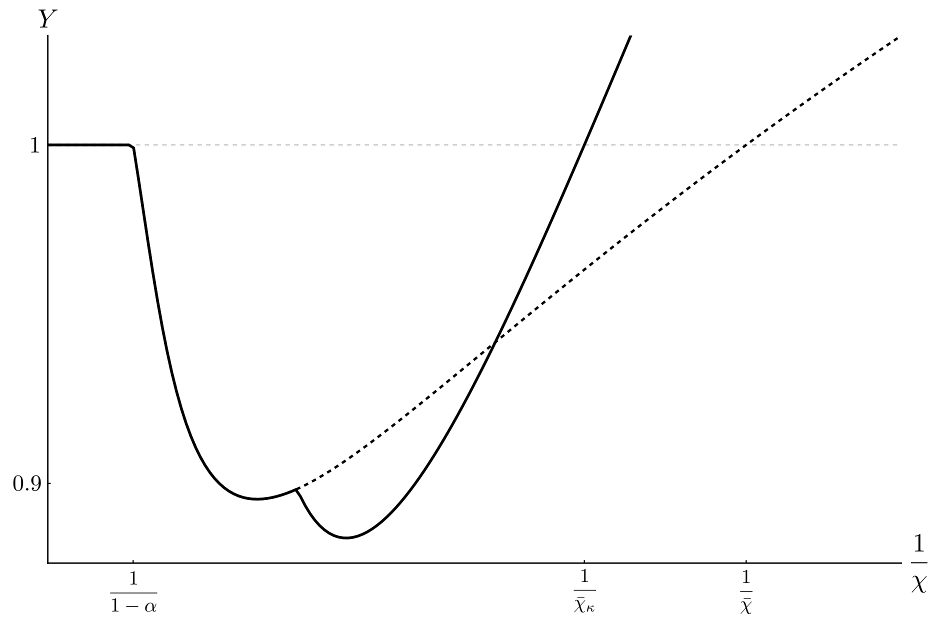
while in the direct-only regime,

$$Y_D = 2F(\bar{\psi}_D) + (\kappa_1 + \kappa_2)w^S \int_{\bar{\psi}_D}^{\infty} \psi \, dF(\psi).$$

The apprenticeship-only output expression is the baseline expression.

Figure B.2 illustrates the mechanism for our baseline parameterization and $\kappa_1 = \kappa_2 = 1/4$. Initially, output declines for the same reason as in the baseline economy: automation reduces the return to apprenticeship and discourages experience accumulation. Once direct entry becomes attractive, some workers substitute away from apprenticeship and enter senior occupations directly. This reallocation does not necessarily raise output. Although direct entrants remain in the modern sector, apprenticeship initially continues to generate more output than direct entry. Workers prefer direct entry because it shifts earnings toward youth. Thus, the same force that drives immiseration in the baseline economy reappears within the modern sector: workers accept lower average production in exchange for a less backloaded earnings profile. Eventually, as automation becomes sufficiently cheap, direct entry no longer entails a substantial output loss relative to apprenticeship and the productivity gains from automation dominate.

Figure B.2: Immiseration Under Expanded Career Paths



Notes: This figure depicts output relative to its pre-automation level as a function of automation efficiency $1/\chi$, with the direct-entry path ($\kappa_1 = \kappa_2 = 1/4$) shown by the solid line and the baseline model without direct entry shown by the dashed line. Both economies are governed by the same preference and technological parameters as the economy depicted in Figure 3.

B.5 Junior vs. Senior-Task Automation

To guide the empirical analysis, we now sketch a multi-sector version of the model in which both junior and senior tasks can be automated. The purpose of this extension is not to characterize a full new general equilibrium, but to derive a sharp sector-level prediction: automation of junior tasks should have more negative effects on a sector than automation of senior tasks.

Overlapping generations and preferences. As in Section 2, workers live for two periods, have CRRA preferences with elasticity of intertemporal substitution $\frac{1}{\gamma}$, and a discount factor β.

Demand. There is a continuum of sectors indexed by $s \in [0,1]$. Sectorial output is aggregated into the final good according to

$$Y_t = \left[\int_0^1 \omega(s)^{\frac{1}{\varepsilon}} y_t(s)^{\frac{\varepsilon-1}{\varepsilon}} \, ds\right]^{\frac{\varepsilon}{\varepsilon-1}}, \qquad \varepsilon > 1.$$

Let $p_t(s)$ denote the price of sector-s output in units of the final good. CES demand implies

$$p_t(s) = \omega(s)^{\frac{1}{\varepsilon}} \left(\frac{y_t(s)}{Y_t}\right)^{-\frac{1}{\varepsilon}}.$$

Technology. Sectorial output is produced by combining junior and senior inputs:

$$y_t(s) = \left(X_t^S(s)\right)^{\alpha(s)} \left(X_t^J(s)\right)^{1-\alpha(s)}. \tag{25}$$

To ensure that there is an experience premium, we again assume $\alpha(s) \geq \frac{1}{2}$.

Junior and senior inputs are produced by combining a continuum of tasks, combined in fixed proportions. That is, for $o \in \{J, S\}$,

$$X_t^o(s) = \min_{\tau \in [0,1]} x_t^o(s, \tau).$$

In sector s and occupation o, the tasks $\tau \leq I^o(s)$ are "automatable", i.e., they can be produced using either labor or the automation technology, while the remaining tasks can only be performed by labor. That is,

$$x_t^o(s,\tau) = \begin{cases} L_t^o(s,\tau) + k_t^o(s,\tau) & \text{if } \tau \leq I^o(s) \\ L_t^o(s,\tau) & \text{if } \tau > I^o(s) \end{cases}$$

where $L_t^o(s,\tau)$ denotes labor input in efficiency units allocated to task τ in sector s, occupation (junior or senior) o, and time t. Similarly, $k_t^o(s,\tau)$ refers to the units of the automation technology. The automation technology converts $\chi^o(s)$ units of sector-s output into one efficiency unit of occupation-o labor.

Occupations, tasks, and comparative advantage. Each worker i is defined by their comparative advantage over sectors $s \in [0,1]$. That is, each worker $i \in I_t$ draws a mapping $\boldsymbol{\psi}_i : [0,1] \to \mathbb{R}^+$, so that their effective units of labor supply in sector s equal $\psi_i(s)$.[13]

At date t', the worker $i \in I_t$ chooses an occupation $o^i_{t,t'} \in \{J, S\}$ and sector $s^i_{t,t'} \in [0,1]$. Let $e^i_{t,t'}(s) \in \{0,1\}$ denote whether worker $i \in I_t$ has accumulated experience in sector s by date t'. Young workers enter the labor market without experience:

$$e^i_{t,t}(s) = 0 \ \ \forall s \in [0,1].$$

Experience is gained by working in junior tasks in the modern sector when young:

$$e^i_{t,t+1}(s) = \mathbf{1}\{o^i_{t,t} = J \cap s^i_{t,t} = s\}.$$

Given occupation and experience, effective labor supply in sector s is:

$$\ell^i_{t,t'}(s) = \begin{cases} \psi^i(s) & \text{if } o^i_{t,t'} = J, \\ \psi^i(s) \cdot e^i_{t,t'}(s) & \text{if } o^i_{t,t'} = S \end{cases}$$

so that experience is again sector-specific.

Labor market. Let $q^o_t(s,\tau)$ denote the price of task τ in occupation o. Since automation is only adopted when it saves costs, this implies

$$q^o_t(s,\tau) = \begin{cases} \min\{w^o_t(s), p_t(s)\chi^o(s)\} & \text{if } \tau \leq I^o(s), \\ w^o_t(s) & \text{if } \tau > I^o(s). \end{cases}$$

[13] Specifically, $\boldsymbol{\psi}_i$ is drawn from a probability distribution over the set of density functions $\mathcal{F} = \left\{ f \geq 0 \mid \int_0^1 f(s)ds = 1 \right\}$. The density function captures a worker's comparative advantage. Since we do not restrict the probability distribution, this nests the case of homogeneous workers (where all draw the uniform distribution).

Because tasks enter in fixed proportions, the price of the occupation-o input is the integral of its task prices. Hence,

$$\int_0^1 q_t^o(s,\tau)d\tau = \begin{cases} p_t(s)(1-\alpha(s))\left(\frac{X_t^J(s)}{X_t^S(s)}\right)^{-\alpha(s)} & \text{if } o = J, \\ p_t(s)\alpha(s)\left(\frac{X_t^J(s)}{X_t^S(s)}\right)^{1-\alpha(s)} & \text{if } o = S. \end{cases} \tag{26}$$

When the automatable tasks are performed by the automation technology, equation (26) gives wages per efficiency unit of labor as

$$\begin{aligned} w_t^J(s) &= \frac{p_t(s)}{1-I^J(s)}\left[(1-\alpha(s))\left(\frac{X_t^J(s)}{X_t^S(s)}\right)^{-\alpha(s)} - I^J(s)\chi^J(s)\right], \\ w_t^S(s) &= \frac{p_t(s)}{1-I^S(s)}\left[\alpha(s)\left(\frac{X_t^J(s)}{X_t^S(s)}\right)^{1-\alpha(s)} - I^S(s)\chi^S(s)\right]. \end{aligned} \tag{27}$$

If automation is not adopted in occupation o, its wage is the corresponding marginal product on the right-hand side of equation (26).

Financial market. Workers can borrow in perfectly competitive financial markets at a gross interest rate R_t.

Worker's optimization problem. A worker $i \in I_t$ chooses occupations $\{o_{t,t}^i, o_{t,t+1}^i\}$ in sectors $\{s_{t,t}^i, s_{t,t+1}^i\}$ and borrows b_t^i (or saves, when negative) to maximize her lifetime utility subject to the budget constraints:

$$c_{t,t}^i \leq w_t^{o_{t,t}^i}\left(s_{t,t}^i\right) \cdot \ell_{t,t}^i\left(s_{t,t}^i\right) + b_t^i \tag{28}$$

$$c_{t,t+1}^i \leq w_{t+1}^{o_{t,t+1}^i}\left(s_{t,t+1}^i\right) \cdot \ell_{t,t+1}^i\left(s_{t,t+1}^i\right) - R_t \cdot b_t^i \tag{29}$$

where $\ell_{t,t}^i(s)$ and $\ell_{t,t+1}^i(s)$ are the worker i's effective units of labor and $w_t^o(s)$ is the wage per effective unit of labor in occupation $o \in \{J, S\}$ and sector s.

Predictions. Consider a reduction in $\chi^o(s)$ at the adoption threshold, where $k^o(s) = 0$, or an increase in $I^o(s)$ such that the marginal task is as costly to produce with the automation technology as with human labor, i.e., $p(s)\chi^o(s) = w^o(s)$.

So-so junior automation reduces sector-specific employment, while senior automation increases it.

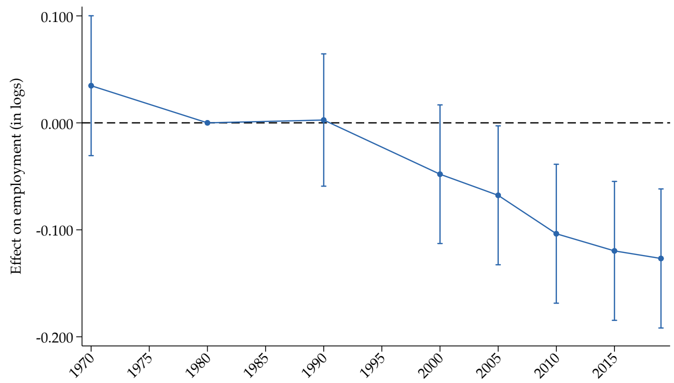
By the envelope theorem, either change has no first-order effect on net output at a fixed allocation. It only rotates wages: more junior automation lowers $w^J(s)$ and raises $w^S(s)$, whereas more senior automation lowers $w^S(s)$ and raises $w^J(s)$. Because each sector has measure zero, these changes do not affect the equilibrium interest rate R or aggregate output Y. Thus, holding sector prices $p(s)$ constant, junior automation increases sector-specific employment in stationary equilibrium, while senior employment decreases it.

The effect on sector-specific prices $p(s)$ does not overturn this. To see this, suppose employment went up in response to so-so junior automation. Since wages rotate against the sector, it implies that prices must have gone up. However, that implies that sector-specific output went up. Since output per worker is not affected, this means that employment went up, a contradiction.

The effect on the wage bill depends on whether the elasticity of substitution between sectors is below or above unity. CES demand implies that $p_s y(s) \propto y(s)^{1-\frac{1}{\varepsilon}}$. Thus when $\varepsilon > 1$, the wage bill moves in the same direction as output and thus employment. If it is below one, it moves in the opposite direction.

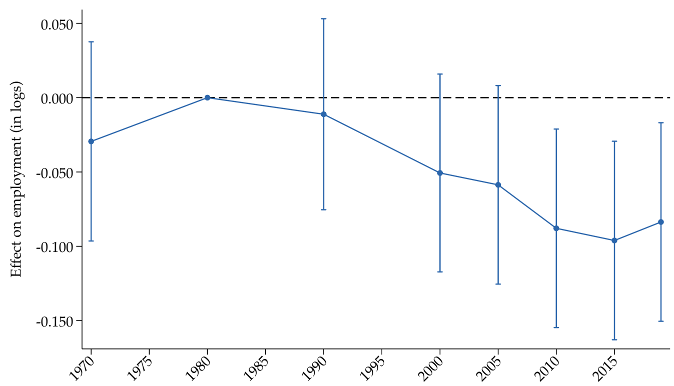
C Empirical Evidence: Additional Figures

Figure C.3: Employment Effects of Junior Bias in Software Exposure



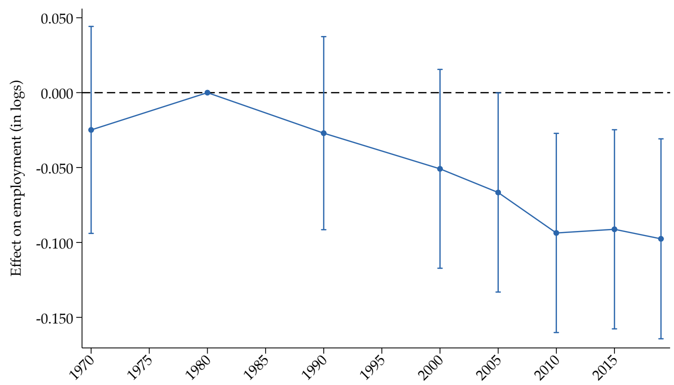
Notes: This figure reports estimates of the parameters $\beta_{t'}$ in equation (15). The dependent variable is an industry's log employment. The coefficients are normalized by the standard deviation of the independent variable so that they reflect effects per standard deviation of junior bias. The regression controls for year- and industry- fixed effects and for the overall exposure of the industry to automation by software, interacted by year. The bars reflect 90% confidence intervals.

Figure C.4: Employment Effects of Junior Bias in Robot Exposure When Using an Alternative Measure of Junior Bias



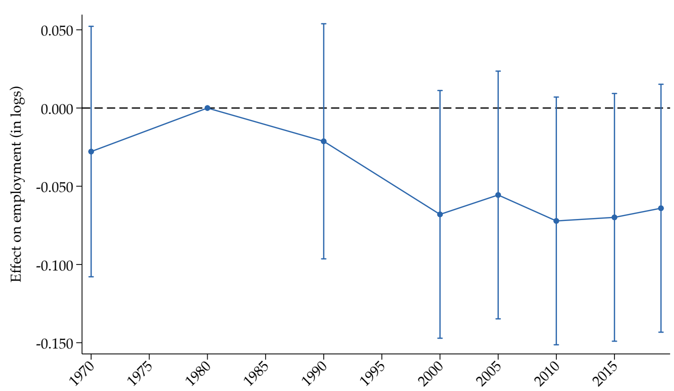
Notes: This figure reports estimates of the parameters $\beta_{t'}$ in equation (15). The dependent variable is an industry's log employment. In contrast to the baseline, junior bias is here defined as the difference between the exposure of workers who are younger vs. older than the industry-specific median age. The coefficients are normalized by the standard deviation of the independent variable so that they reflect effects per standard deviation of junior bias. The regression controls for year- and industry- fixed effects and for the overall exposure of the industry to automation by software, interacted by year. The bars reflect 90% confidence intervals.

Figure C.5: Employment Effects of Junior Bias in Robot Exposure When Computing Exposure Based on 1990 Census



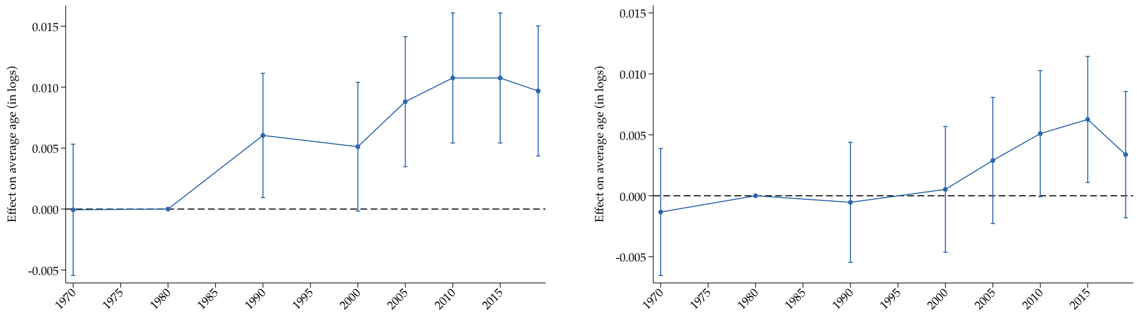
Notes: This figure reports estimates of the parameters $\beta_{t'}$ in equation (15). The dependent variable is an industry's log employment. Exposure to automation and the junior bias in automation are computed based on data in the 1990 Census rather than the 1980 Census in the baseline. The coefficients are normalized by the standard deviation of the independent variable so that they reflect effects per standard deviation of junior bias. The regression controls for year- and industry- fixed effects and for the overall exposure of the industry to automation by robots, interacted by year. The bars reflect 90% confidence intervals.

Figure C.6: Employment Effects of Junior Bias in Robot Exposure When Using an Alternative Occupational Exposure Measure



Notes: This figure reports estimates of the parameters $\beta_{t'}$ in equation (15). The dependent variable is an industry's log employment. These estimates rely on exposure measures is constructed by Graetz and Michaels (2018) rather than those by Webb (2019) as in the baseline. The coefficients are normalized by the standard deviation of the independent variable so that they reflect effects per standard deviation of junior bias. The regression controls for year- and industry- fixed effects and for the overall exposure of the industry to automation by robots, interacted by year. The bars reflect 90% confidence intervals.

Figure C.7: Age Effects of Junior Bias in Automation Exposure



(a) Robots (b) Software

Notes: This figure reports estimates of the parameters $\beta_{t'}$ in equation (15). The dependent variable is an industry's log average age. The coefficients are normalized by the standard deviation of the independent variable, so that they reflect effects per standard deviation of junior bias. The regressions control for year and industry fixed effects and for the overall exposure of the industry to automation, interacted by year. The bars reflect 90% confidence intervals.