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RESEARCH INSTITUTE FOR DEVELOPMENT, GROWTH AND ECONOMICS

SINCE 2014

Where is the Beef? Supply Chains and Carbon Emissions in the Amazon

Marcos Barrozo

RIDGE Working Paper 018

This paper was presented at the 2025 RIDGE December Forum

The Unequal Impact of Public Mistrust on Labor Markets: Evidence from an Environmental Disaster*

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August 26, 2025

Abstract

This paper examines the indirect effects of an unprecedented environmental disaster, caused by an inadequately regulated mining dam, on labor markets in Brazil. Using matched employer-employee data and georeferenced locations of tailings dams, we compare endangered municipalities downstream of active dams with safer upstream municipalities nearby, excluding those physically damaged by actual disasters. To interpret our findings, we present a monopsony model where workers value local amenities and differ in mobility costs and labor demand. Following a preventable disaster elsewhere, results show that wages of nonfarm high-skilled workers increase by 6.6%–9.8% more downstream than upstream, along with a 6%–9.5% reduction in employment. We calculate that the median high-skilled worker requires at least \$4,768 more per year to remain downstream. Among high-skilled workers, women and non-white workers are less likely to receive additional compensation and more prone to relocate compared to men and white workers. For low-skilled workers, the effects on wages and employment are insignificant, suggesting high mobility costs. Limited mobility is also observed among high-skilled workers in micro establishments or with longer tenure. Our findings indicate that environmental risks resulting from lax regulation increase labor costs, but mobility constraints prevent many workers from being adequately compensated for these risks.

Keywords: Environmental Disaster, Public Trust, Indirect Effect, Imperfect Labor Markets, Risk Perception, Wage Differentials.

JEL Code: D83, J31, J42, K32, Q51, R11.

*We are grateful to Graham Beattie, Stephen Billings, Wesley Blundell, Paola D'Orazio, Michail Fragkias, Maurice MacDonald, Lee Parton, Cort Rodet, Breno Sampaio, Italo Santos, Andrew Smyth, seminar participants at Boise State University, Catholic University of Brasilia, UFOP (Mariana Talks), and PIMES-UFPE, and conference participants at MWIEDC, BCB Conference, AESS Conference, and AERE Summer Conference for helpful comments and suggestions. Philipp Ehrl thanks the Federal District Research Foundation (FAP-DF) and the National Council for Scientific and Technological Development (CNPq) for their financial support (Grant Numbers 00193-00001794/2023-77 and 406860/2023-8, respectively).

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1 Introduction

On November 5, 2015, the collapse of a tailings dam in Mariana, Brazil, resulted in one of the most devastating environmental disasters in the country's history. The incident received extensive coverage on national television, with viewers witnessing in real time as 50 million cubic meters of hazardous mine waste buried downstream villages and polluted over 600 km of the Doce River before it reached the Atlantic Ocean (Escobar, 2015).[1] In addition to the 19 fatalities directly caused by the dam collapse, the spilled mud was found to contain high levels of heavy metals (Davila et al., 2020), which reduced birth weight and increased the infant mortality rate in downstream villages (Carrillo et al., 2020). This disaster unveiled critical regulatory flaws in the mining industry, prompting a review and subsequent strengthening of safety regulations (Silva, Muniz and Tabak, 2023). However, less than four years later, on January 25, 2019, another major tailings dam failed in Brumadinho, just 123 km from Mariana. Although this incident released a smaller volume of mining waste — approximately 13 million cubic meters — it directly resulted in 270 fatalities.

Despite the tragedies caused by these disasters, environmentally hazardous developments may create jobs, having multiplier effects and benefiting local communities (e.g., Greenstone, 2002; Duflo and Pande, 2007; Lopes et al., 2023). Furthermore, if local communities were well informed about the risks and potential damages, market mechanisms should, in theory, compensate them in advance (Tiebout, 1956; Coase, 1960; Banzhaf and Walsh, 2008). On the other hand, if information is opaque, environmental accidents may erode public trust in companies and regulatory authorities, thereby increasing the external costs of such projects everywhere. Still, the efficiency of markets in pricing external costs depends on the ability of local populations to negotiate compensation (Banzhaf, Ma and Timmins, 2019).

In this paper, we examine the dam failure in Mariana as an information shock that drew attention to the consequences of such incidents, estimating its indirect impact on

[1] It also received extensive coverage in international outlets. For example, see articles on Reuters, ABC News, BBC, The Gaurdian, and The Financial Times.

worker compensation in areas exposed to the same type of risk. To identify these areas, we use the georeferenced locations of active dams and map river flows through watersheds, restricting our sample to municipalities near large tailings dams that were not physically damaged by previous accidents.[2] Using a difference-in-discontinuities (diff-in-disc) approach, we compare municipalities downstream of dams with upstream municipalities nearby. Although both areas are subject to similar economic shocks and trends, downstream areas would face worse damages if a close dam were to fail. If the new information on potential damages raises workers' risk perception, they may demand higher wages to remain downstream. By excluding municipalities directly impacted by dam collapses, this approach isolates the effect of public mistrust over safety regulations.

With the use of matched employer-employee data from 2010 to 2019, we investigate which types of workers are more likely to receive compensation for increased risk perception, relocate, or remain without additional compensation. Our sample includes all regular workers formally registered by an employer in Brazil, excluding public servants and those employed in mining or agriculture. To account for spillovers from the mining industry and other local shocks, our diff-in-disc design controls for the time-varying relationship between labor outcomes and distance to the shortest dam. Additionally, to compare treated and untreated municipalities in close proximity, we interact the treatment dummy with the distance to a dam, centering our estimates on areas very close to a tailings dam. To ensure the robustness of our findings, we apply various distance bandwidths to a rectangular kernel regression.

Over the four years following the first incident in Mariana, ending shortly after the second incident in Brumadinho, we find that the wages of high-skilled workers increased by 6.6% to 9.8% more downstream than upstream, representing an annual cost per median worker between $1,851 and $2,749 PPP. This wage increase was accompanied by a 6% to 9.5% reduction in the number of high-skilled workers. Among low-skilled workers, we observe a significant rise in resignations, consistent with a negative supply shock. However, the

[2] Before the incident in Mariana, two other tailings dam failures occurred in the state of Minas Gerais, near Cataguases, in 2003 and 2007. However, they were not as damaging as the one in Mariana.

estimated impacts on their wages and employment levels are small and mostly insignificant. These findings suggest that high-skilled workers possess greater bargaining power, enabling them to demand higher wages or relocate, whereas low-skilled workers are not compensated.

Among high-skilled workers, we also find considerable variation in impacts based on individual characteristics, sub-occupation, and firm size. The positive effect on wages is slightly smaller for female, non-white, and non-managerial workers than male, white, and managerial workers, respectively. At the same time, the negative impact on local employment is about three times larger for female, non-white, and non-managerial workers. In terms of job tenure, high-skilled workers employed for more than four years exhibit smaller wage increases than other workers and no significant change in their probability of resignation. Regarding firm size, only establishments with 100 employees or more present a large and significant wage increase. In contrast, only smaller establishments, with fewer than 100 employees, show a significant reduction in high-skilled employment.

To explain this heterogeneity, we present a model of imperfect competition in labor markets, drawing from Manning (2003, 2011), Card et al. (2018), and Lamadon, Mogstad and Setzler (2022), where workers value local amenities and incur distinct mobility costs. Moreover, to fully account for differences in labor demand, our model considers that the elasticity of substitution between skill groups varies across tasks, which correlates with worker productivity. On the one hand, the lack of significant impacts on employment and wages for the low-skilled group and long-term high-skilled workers is consistent with high mobility costs, resulting in an inelastic labor supply. On the other hand, the remaining heterogeneity within the high-skilled group is aligned with differences in labor demand.

These differences in labor demand within the high-skilled group allow us to simulate potential combinations of labor supply elasticity and reductions in amenity value caused by dam failures elsewhere. The simulations reveal that female, non-white, less educated, and non-managerial workers exhibit either higher supply elasticity or larger reductions in amenity value, or both, compared to male, white, highly educated, and managerial workers, respectively. This indicates that subgroups facing higher demand elasticity are also more prone to relocate. In terms of firm size, large firms not only have a more inelastic demand for high-skilled labor but also face a more elastic labor supply. For micro establishments, with fewer than 20 employees, the implied labor supply appears inelastic. Finally, the simulations imply that, on average, a high-skilled worker is willing to accept a job downstream if their wage is at least 17% higher than upstream, corresponding to an increase in the willingness to accept (WTA) of $4,768 PPP per year for the median worker. Based on the value of statistical life (VSL) of $13 million (Kearsley, 2024), this WTA is equivalent to a perceived risk of one additional death per 2,727 individuals.

Additional results presented in this paper and the Online Appendix confirm the robustness and consistency of our findings. The estimated effects on labor outcomes remain robust to a series of bandwidths for the distance to tailings dams, alternative definitions for tailings dams, and different classifications of worker skills. Moreover, no diff-in-disc estimation exhibits a clear differential trend prior to the first disaster. Regarding the potential mechanisms, we find no evidence that education drives the differences between low- and high-skilled workers. Among workers with secondary education, those in high-skilled occupations also experience significant wage increases, while those in low-skilled occupations face no significant change. In general, despite the increase in resignation rates, almost no subgroup of low-skilled workers has its wages or employment significantly affected. Furthermore, the reduction in high-skilled employment is primarily explained by higher resignation rates, while the effects on layoffs are largely insignificant. To some extent, high-skilled employment also declined due to the smaller number of new workers entering the local market.

The contribution of this paper is fourfold. First, we show that the effects of rare but high-loss hazard events extend beyond the directly affected and nearby areas. In this respect, our study contributes to the literature on the relationship between natural or environmental disasters and labor markets (Vigdor, 2008; Belasen and Polachek, 2009;

Deryugina, Kawano and Levitt, 2018; Kirchberger, 2017; Lima and Barbosa, 2019; Indaco, Ortega and Taşpınar, 2020; Groen, Kutzbach and Polivka, 2020; Hoang et al., 2020; Boustan et al., 2020) and the capitalization effects of environmental quality and hazardous facilities (Davis, 2004; Greenstone and Gallagher, 2008; Bin and Landry, 2013; Currie et al., 2015; Ortega and Taşpınar, 2018; Boslett and Hill, 2019; Christensen, Keiser and Lade, 2023), which is mostly focused on direct effects. Our findings also align with studies on the indirect effects of natural disasters on adaptive behavior (Brookshire et al., 1985; Frame, 1998; Gallagher, 2014; Bernstein, Gustafson and Lewis, 2019; Gibson and Mullins, 2020) and the impact of information disclosure on self-exposure to health risks and demand for environmental quality (Madajewicz et al., 2007; Shimshack, Ward and Beatty, 2007; Jalan and Somanathan, 2008; Neidell, 2009; Ito and Zhang, 2020; Tu et al., 2020; Barwick et al., 2024).

Second, we demonstrate through a natural experiment that environmental risks are also capitalized in labor markets. The seminal models of Rosen (1979) and Roback (1982) assert that the value of amenities is a combination of prices in the land and labor markets.[3] The present study contributes to the growing body of experimental and quasi-experimental evidence on wage differentials arising from hazard exposure (Viscusi and O'Connor, 1984; Lee and Taylor, 2019; Lavetti, 2020; Braakmann, Eberth and Wildman, 2022; Wissmann, 2022; Gian et al., 2024).[4] To the best of our knowledge, this study is among the first to examine the indirect impact of environmental disasters on wage differentials.

Third, by exploiting a labor supply shock, we infer differences in demand and supply elasticities between skill groups and among high-skilled workers. For instance, our findings indicate that micro establishments face a more elastic supply of high-skilled labor than large establishments, whereas the lower mobility of longer-term workers is primarily driven by a

[3]Property rents contain all the information necessary to value amenities only if wages are solely a function of productivity (Currie et al., 2015; Albouy, 2016). As theorized by Thaler and Rosen (1976), Rosen (1986), and Lamadon, Mogstad and Setzler (2022), amenities and hazard exposure can create wage differentials, weakening the link between wages and productivity.

[4]See Viscusi and Aldy (2003) and Lavetti (2023) for a broader review of the empirical literature.

more inelastic supply. These findings provide new insights into the literature on monopsony labor markets (Boal and Ransom, 1997; Bhaskar, Manning and To, 2002; Bassier, Dube and Naidu, 2022; Lamadon, Mogstad and Setzler, 2022) and labor mobility (Farber, 1999; Bound and Holzer, 2000; Moretti, 2011; Machin, Salvanes and Pelkonen, 2012; Adda and Dustmann, 2023; Hornbeck and Moretti, 2024). Furthermore, high-skilled workers more likely to face discrimination are also more prone to relocate to other markets. This result does not align with the idea of taste-based discrimination increasing search costs (Black, 1995; Caldwell and Danieli, 2024).

Fourth, we examine an underexplored aspect of environmental justice (Mohai, Pellow and Roberts, 2009; Banzhaf, Ma and Timmins, 2019). According to Timmins and Vissing (2022), local communities may lack the bargaining power or resources to secure fair compensation for environmental risks, suggesting inefficiencies in the Coasian bargaining process. Our study argues that frictions in labor markets prevent low-skilled workers from being compensated for hazard exposure, reinforcing the nexus between environmental quality and income inequality.[5] More broadly, it sheds light on labor market factors that contribute to the low valuations of environmental quality often observed in developing countries (Greenstone and Jack, 2015).

The remainder of this paper is organized as follows. Section 2 outlines the theoretical framework for the interpretation of our results. Section 3 describes the data sources, sample restrictions, and variable construction. Section 4 explains our empirical strategy. Section 5 presents the estimated effects on wages, employment, and resignations, along with calculations of demand and supply elasticities and WTA. Section 6 concludes the paper. The Online Appendix contains the solutions for our theoretical model and additional results.

[5]This nexus is also evident in studies on the relationship of income with avoidance behavior and preventive measures (e.g., Zivin, Neidell and Schlenker, 2011; Beatty, Shimshack and Volpe, 2019; Chen et al., 2020). See Drupp et al. (2024) for a review of the interaction between environmental quality and income inequality.

2 Conceptual Framework

This section provides a conceptual model to explain the changes in local labor markets following an environmental disaster elsewhere. Our model is characterized by the following elements: workers' utility depends on firm-specific and local amenities, including environmental risks; firm-level labor supply is not perfectly elastic; low- and high-skilled workers differ in mobility costs (or rents obtained from current employer); and firms exhibit heterogeneous elasticity of substitution between skills. Considering the proximity of upstream and downstream municipalities in our empirical analysis, we also assume that the price of capital is exogenous and remains the same after a disaster elsewhere.

In a model with a perfect competitive equilibrium and free labor mobility (e.g., Rosen, 1979; Roback, 1982; Acemoglu and Autor, 2011; Moretti, 2011), a reduction in local amenities increases wages in the short run, regardless of workers' skills. In the long run, though, if the price of capital is fixed, the stock of capital should decline, reducing labor productivity. As a result, labor demand becomes perfectly elastic, and the labor supply shock reduces employment but has no impact on wages.[6]

In our model, the long-run effect on wages is null only if the skill groups are perfect substitutes or have identical mobility costs. Under imperfect substitution and distinct mobility costs, a rise in environmental risks should impact wages. Still, wages should not necessarily increase for all skill groups. While employment should, if anything, decline for all skill groups, wages must increase only for the group with lower mobility costs. For the other group, wages may decline or remain constant despite the reduction in amenities.

Furthermore, variations in the elasticity of labor demand across firms and workers would be limited unless the elasticity of skill substitution differs across tasks. Incorporating this heterogeneity allows us to account for empirical patterns in wages and employment that

[6] As shown in Dustmann, Schönberg and Stuhler (2017), a labor supply shock affects the wages of low- and high-skilled workers in the long run only if local capital supply is not perfectly elastic. They also demonstrate that wages may change under perfectly elastic capital if the model includes three skill groups. However, the labor supply shock must be strictly monotonic across these groups, which does not necessarily apply to our context.

cannot be explained by differences in mobility costs or firm-specific amenities.

2.1 Worker Preferences and Labor Supply

Following Card et al. (2018) and Lamadon, Mogstad and Setzler (2022), we consider that workers have heterogeneous preferences and skills. To simplify, we consider only two types of workers, high-skilled (H) and low-skilled (L). As in Dustmann, Schönberg and Stuhler (2017), we assume that workers' skill levels are exogenous and cannot change. Since we examine the effect of local amenities, we also assume that each location has only one firm. Later, we discuss the implication of allowing multiple firms in the same location.

For worker i with skill level $x \in \{H, L\}$, the indirect utility of working at firm j is

$$v_i(j; x) = \log W_j(x) + \log G_j + \beta_x \epsilon_{ij},$$

where $W_j(x)$ represents the wage paid by firm j to a worker with skill level x, G_j denotes the value of the amenities that firm j offers, and ϵ_{ij} denotes worker i's idiosyncratic preference for working at firm j. In our context, assuming that all workers have the same degree of risk aversion, the value G_j comprises the certainty equivalent cost of working for firm j if it requires living in an area subject to the risk of an environmental accident.

More generally, while the value G_j implies vertical differentiation between firms — i.e., for the same worker, employers vary in terms of amenities —, the component $\beta_x \epsilon_{ij}$ captures the horizontal differentiation — i.e., workers are heterogeneous in their preferences over the same firm (Lamadon, Mogstad and Setzler, 2022). The horizontal differentiation is determined by the skill-specific parameter $\beta_x \geq 0$. The larger the β_x, the more dispersed workers with skill x are, increasing horizontal differentiation among employers.

One interpretation is that β_x represents the workers' search or mobility costs. A larger β_x implies that it is more costly to workers with skill x to move from one firm to another (or from one city to another). As a result, workers receive rents from their current employers because an identical job cannot be found at zero cost (Manning, 2011). To facilitate our analysis, we assume that β_x is exogenous and, without loss of generality, $\beta_L \gg \beta_H$.[7]

To derive the labor supply function, we assume that ϵ_{ij} is drawn from a standard Gumbel distribution. Then, for worker i, the vector $\overrightarrow{\epsilon}_i = (\epsilon_{i1}, \ldots, \epsilon_{iJ})$ has a multinomial logit structure, and, assuming a large number of firms, the supply of skill x to firm j is

$$N_j\left(x, W_j(x)\right) = \lambda_x \left[W_j(x) G_j\right]^{1/\beta_x}, \tag{1}$$

where $\lambda_x > 1$ is a skill-specific constant common to all firms. With this function, the wage elasticity of skill supply is $\varepsilon_S(x) = 1/\beta_x$. That is, the greater the dispersion of workers with skill x, the more inelastic the supply of this skill to any firm.

2.2 Firm Technology and Labor Demand

On the demand side of the labor market, we consider heterogeneous firms that differ in terms of total factor productivity (TFP), A_j, amenities, G_j, and task, a_j. Also, the relative productivity of high- and low-skilled workers and the elasticity of substitution between skills vary across tasks. Since each firm performs one task, the comparative advantage of each skill and the substitutability between skills differ across firms.

Firm j is assumed to have the following production function:

$$Y_j\left(\mathbf{E}_j(a), K_j; a = a_j\right) = A_j \left[\mathbf{E}_j(a)\right]^{1-\alpha} K_j^{\alpha},$$

where K_j denotes the amount of capital, $\mathbf{E}_j(a)$ is the efficiency units of labor, and α is the distribution parameter between labor and capital, with $\alpha \in (0,1)$.[8]

Following Dustmann, Schönberg and Stuhler (2017), the efficiency units of labor in firm j, $\mathbf{E}_j(a)$, is determined by a CES function:

$$\mathbf{E}_j(a) = \left(\theta_H(a)\left[E_j(H)\right]^{\delta_a} + \theta_L(a)\left[E_j(L)\right]^{\delta_a}\right)^{1/\delta_a},$$

where $E_j(x)$ is the number of employees with skill x in firm j, $\theta_x(a)$ is the task productivity

[7] This assumption is consistent with the empirical evidence in Bound and Holzer (2000) and Machin, Salvanes and Pelkonen (2012).

[8] We could also consider a CES production function. However, considering that the price of capital r is exogenous, the long-run elasticities of employment and wages to amenities would remain the same.

schedule, with $\theta_H(a) + \theta_L(a) = 1$, and δ_a is the parameter determining the substitution between the two types of skills, with $\delta_a \leq 1$. To analyze the heterogeneity of our empirical results across firms, we consider that $\delta_a = \delta(a)$ varies with the task. If $\delta_a = 1$, then high and low skills are perfect substitutes for task a. If $\delta_a \to -\infty$, then neither skill can be substituted by the other in task a.

As in Acemoglu and Autor (2011), we assume that $\theta_L(a)/\theta_H(a)$ is continuously differentiable and strictly decreasing in a. In a model with a competitive labor market and perfect substitutability between skill groups, this assumption implies that each task is assigned to a single skill group and the employment of high-skilled workers increases with a. However, since we consider that firms are price makers and the elasticity of substitution between skills varies across firms, firms can optimally employ both skill groups to perform the same task and high-skilled employment does not necessarily increase with a. As described in Section A.2 of the Online Appendix, a sufficient condition for high-skilled employment to increase with a is that $\beta_L \to \infty$ and the elasticity of substitution between skills decreases with a — i.e., $\delta'(a) \leq 0$.

Firm j maximizes its profit subject to its employment level being equal to its labor supply, $E_j(x) = N_j(x, W_j(x))$ with $x \in \{H, L\}$. In Section A.3 of the Online Appendix, we derive the following skill-specific labor demand curve:

$$\begin{cases} d\log W_j(x) = (1-\delta_a)s_{x'}(a)\left[d\log E_j(x') - d\log E_j(x)\right] & \text{if } \delta_a > -\infty, \\ d\log E_j(x) = d\log E_j(x') & \text{if } \delta_a \to -\infty, \end{cases} \tag{2}$$

with $x, x' \in \{H, L\}$ and $x' \neq x$, where $s_{x'}(a)$ denotes the factor share of skill x' in task a.

2.3 Elasticities of Employment and Wages to Amenities

With equations (1) and (2), we obtain the following elasticity of skill-specific employment to amenities:

$$\frac{d\log E_j}{d\log G_j}(x,a) = \begin{cases} \dfrac{1}{\beta_x + s_{x'}(a)\frac{(1-\delta_a)\left(\beta_{x'}-\beta_x\right)}{1-\delta_a+\beta_{x'}}} & \text{if } \delta_a > -\infty \\ 0 & \text{if } \delta_a \to -\infty, \end{cases} \tag{3}$$

and the elasticity of wages to amenities:

$$\frac{d\log W_j}{d\log G_j}(x,a) = \begin{cases} -\dfrac{s_{x'}(a)(1-\delta_a)\left(\beta_{x'}-\beta_x\right)}{\beta_x\left(1-\delta_a+\beta_{x'}\right)+s_{x'}(a)(1-\delta_a)\left(\beta_{x'}-\beta_x\right)} & \text{if } \delta_a > -\infty \\ -1 & \text{if } \delta_a \to -\infty, \end{cases} \tag{4}$$

with $x, x' \in \{H, L\}$ and $x' \neq x$.

Equations (3) and (4) are key for interpreting the observed effects of an environmental disaster in labor markets elsewhere. Note that both elasticities depend on the substitutability of skills in the task (δ_a) and workers' dispersion (β_x). Since $\delta_a \leq 1$ and $s_{x'}(a) \in (0,1)$, the employment elasticity in equation (3) is greater than or equal to zero. Thus, after an environmental disaster elsewhere, if the value of amenities decreases for all types of workers ($d\log G_j < 0$), the employment of any skill by firm j should, if anything, decrease. This negative effect tends to be weaker whether skill group x is very dispersed ($\beta_x \to \infty$) or, for task a, skill x is hardly replaceable by the other skill ($\delta_a \to -\infty$).

In the following, we provide five possible scenarios predicted by our model, considering that an environmental disaster decreases the value of amenities for both skill groups ($d\log G_j < 0$). Section A.4 of the Online Appendix presents derivations and further details.

Scenario 1: employment and wages remain constant. This occurs only if workers are very dispersed ($\beta_x \to \infty$). Moreover, a sufficient condition is that skill group x is largely employed in tasks with elasticity of substitution between skills greater than one — i.e., $\delta_a > 0$.

Scenario 2: employment declines, and wages remain constant. This occurs only if skill group x has limited dispersion ($\beta_x < \infty$). In addition, a sufficient condition is that this group is largely employed in tasks where skills are perfect substitutes — i.e. $\delta_a = 1$.

Scenario 3: employment declines, and wages increase. With $\beta_L > \beta_H$, this is the predicted outcome for high-skilled workers if they are largely employed in tasks where skill groups are imperfect substitutes — i.e., $-\infty < \delta_a < 1$.

Scenario 4: employment and wages decline. With $\beta_L > \beta_H$ and $\beta_L < \infty$, this is the predicted outcome for low-skilled workers if they are largely employed in tasks where skill groups are imperfect substitutes — i.e., $-\infty < \delta_a < 1$.[9]

Scenario 5: employment remains constant, and wages increase at the same rate that the value of amenities declines — i.e., $d \log W_j(x,a) = -d \log G_j$. This occurs if skill group x is largely employed in tasks where skills cannot substitute each other — i.e., $\delta_a \to -\infty$.[10]

2.4 Heterogeneity Across Workers Within Skill Groups

Those five scenarios can also be extended to explain differences within skill groups (e.g., male and female high-skilled workers), depending on their heterogeneity in terms of mobility (β_x) and task substitutability (δ_a). For example, differences in mobility costs may arise if a subgroup of workers faces taste-based discrimination (Black, 1995). In contrast, differences in tasks may occur if a subgroup of workers is perceived as less productive than others (Arrow, 1973; Phelps, 1972; Aigner and Cain, 1977), sorting them into tasks with lower comparative advantage relative to the other skill group.

In our model, if differences in β_x play a significant role in explaining the heterogeneity within skill groups, we should observe larger reductions in employment combined with larger increases in wages, which result from a smaller β_x. For a larger β_x, we should observe a lower reduction in employment combined with a smaller increase (or larger reduction) in wages.

Only if differences in tasks (δ_a) play a more significant role, we can observe larger reductions in employment combined with smaller increases in wages, which result from a

[9]Only in the short run, when capital is fixed ($d \log K_j = 0$), the wages of low-skilled workers could increase if the difference between β_L and β_H is large enough. See Section A.6 of the Online Appendix.

[10]In Sections A.4 and A.6 of the Online Appendix, we demonstrate that this scenario can occur only if firms reduce their capital following a disaster. If capital is fixed, then this scenario cannot occur.

higher elasticity of substitution. For a lower elasticity of substitution, we should observe a lower reduction in employment combined with a larger increase in wages.

2.5 Heterogeneity Across Firms

According to Lamadon, Mogstad and Setzler (2022), two factors explain differences in firm size: TFP (A_j) and amenities (G_j). As shown in the elasticities above, differences in TFP should not explain the heterogeneous effects across firms, unless A_j is correlated with task a. Likewise, if all firms in the same area offer the same amenities, a shock in local amenities would have the same impact on large and small firms.

To understand how differences in amenities explain heterogeneous impacts across firms, suppose that firm amenities, G_j, are the sum of firm-specific amenities, q_j, and local amenities, p_j. That is, firm-specific amenities perfectly substitute local amenities. Then, we have the following elasticity of employment to local amenities:

$$\begin{aligned}\frac{d\log E_j}{d\log p_j}(x,a) &= \frac{d\log E_j(x,a)}{d\log G_j}\frac{d\log G_j}{dp_j}p_j\\ &= \frac{d\log E_j(x,a)}{d\log G_j}\frac{p_j}{q_j+p_j}.\end{aligned}$$

This elasticity implies that high-amenity firms, denoted by B, face a lower impact compared to low-amenity firms, denoted by S, because for any a and $x \in \{H, L\}$,

$$\frac{d\log D_B}{d\log D_S}(x,a) = \frac{q_S+p}{q_B+p} < 1 \quad \text{with } q_B > q_S.$$

Similarly, the impact on wages is lower in high-amenity firms because

$$\frac{d\log W_B}{d\log W_S}(x,a) = \frac{q_S+p}{q_B+p} < 1 \quad \text{with } q_B > q_S.$$

Hence, differences in firm-specific amenities may explain heterogeneous effects across firms in the same area, as long as wages and employment are more sensitive in low-amenity firms.

However, differences in firm-specific amenities cannot explain an empirical scenario where some firms have more sensitive wages while others have more sensitive employment. In this case, a possible explanation is that the TFP is correlated with task a. For example, if δ_a

decreases with the TFP (i.e., the largest firm cannot substitute skills), then larger firms will present a less negative impact on employment and a more positive impact on wages.

3 Data and Descriptive Statistics

This section describes the process of building our dataset from multiple sources. We begin with the geolocations of large tailings dams, provided by the Brazilian National Water and Basic Sanitation Agency (ANA). For each dam, we identify downstream municipalities exposed to a potential failure using a database of hydrographic basins, also provided by ANA. Among these municipalities, we exclude those directly affected by the incidents in Mariana and Brumadinho. The remaining downstream municipalities are paired with upstream municipalities nearby, not exposed to the same risk. Finally, we use administrative data to gather information on workers in all formal business establishments in the selected municipalities, excluding those in mining, agriculture, and public services.

3.1 Locations of Tailings Dams

Since 2015, ANA has monitored the safety of dams through its National Information System (SNISB). ANA's annual reports provide the geocoded locations of all dams in Brazil, along with information on their function, type of construction, classification of failure risk and potential damage, age, size, and capacity. Although the reports from 2015 and 2016 list almost all dams in the country, they lack detailed information on size, function, and potential damage for most dams. To address these limitations, we use the 2017 report, which includes more comprehensive data, to identify tailings dams.

We refer to tailings dams as those used to retain hazardous residuals from industrial and mining activities. Among these, we restrict our sample to dams officially classified by ANA as large. Namely, those with a structural height exceeding 15 meters or a capacity of more than three million cubic meters (World Bank, 2014). To verify the robustness of our findings, we also distinguish dams based on potential damage. ANA categorizes potential damage into high, moderate, and low according to a combination of criteria: volume of the reservoir, potential human life losses, and the environmental and socioeconomic impacts of a failure (World Bank, 2014). The locations of all tailings dams are displayed in Figure S1 of the Online Appendix.

3.2 Hydrographic Basins and the Identification of Exposed Areas

Our empirical strategy relies on identifying whether a municipality is directly exposed to the risk of a dam failure. To classify municipalities by exposure, we use the Ottocoded Hydrographic Database (BHO) provided by ANA. The BHO applies the Pfafstetter system, which assigns numerical codes to hydrographic basins, allowing a hierarchical subdivision of drainage networks (Verdin and Verdin, 1999). These basins are organized into levels, from level 1 (major river basins) to level 6 (drainage units within watersheds).

We use level 6 basins, or drainage units, to trace the watercourses starting at each tailings dam until they reach the ocean or cross the country's border. The left-hand map in Figure 1 provides an example of a watercourse delineated using drainage units, along with the downstream municipalities it serves. After mapping the downstream areas for each dam, we classify municipalities as "treated," if located downstream, and "untreated," if located upstream. For example, for a single dam, the right-hand map in Figure 1 shows the treated municipalities in red and the untreated ones in green. When combining all tailings dams, municipalities downstream of at least one dam are considered treated in our analysis. Untreated municipalities are those with no tailings dam located upstream.

[Figure 1 about here]

For municipalities with a tailings dam within their jurisdiction, we cannot determine whether workers live and work in downstream or upstream areas. For this reason, we exclude these municipalities from our analysis and focus solely on the adjacent ones. To ensure that we capture the indirect effects of dam failures, we also exclude municipalities located downstream or within 100 km of the dams that collapsed in Mariana, in 2015, and Brumadinho, in 2019. Finally, for each dam, we include treated municipalities only if we can also identify an untreated municipality within the same radius.

Based on the locations of large tailings dams, the treated and untreated municipalities in our final sample are displayed in Figure 2. In this map, we only consider municipalities within 75 km of a dam. However, in our empirical analysis, the radius varies between 60 km and 90 km. Figure S2 of the Online Appendix exhibits the selected municipalities based on other types of tailings dams.

[Figure 2 about here]

3.3 Other Municipality Data

In addition to the sample restrictions above, we exclude municipalities that received royalties from oil extraction between 2008 and 2019 and those with a population exceeding 500,000 in 2010. These municipalities, most of which are located downstream of a tailings dam, are more likely to have followed distinct labor market trends compared to upstream municipalities. In particular, a few large municipalities could disproportionately influence our point estimates due to their excessive number of workers relative to smaller municipalities. Moreover, royalties, which experienced a steep growth in the 2010s, have a significant impact on wages and employment in Brazil (Cavalcanti, Da Mata and Toscani, 2019).

While data on royalties are obtained from the National Agency for Petroleum, Natural Gas and Biofuels (ANP), population sizes come from the Demographic Census of 2010. For our descriptive analysis, we also collect data from the Brazilian Institute of Geography and Statistics (IBGE), such as municipal GDP, employment per industry, life expectancy, average schooling, and average housing rent.

3.4 Matched Employer-Employee Data

All the outcomes in our analysis come from the Annual Social Information Report (RAIS), provided by the Ministry of Labor for the years 2010 to 2019 (the last year to which we have access for this study). RAIS contains information on every registered employee in Brazil, such as salary, hours worked, tenure, type of contract, occupation, gender, race, education, and reason for dismissals. It also has data on workers' employers, such as location, industry, and number of employees. For this study, a firm or employer is defined as a business establishment, regardless of whether it operates as a branch or is owned by another company.

Based on workers' occupation, we classify them into high- and low-skilled groups. According to the Brazilian Occupation Classification (CBO), the high-skilled group includes top-level managers, organizational leaders, directors, and professionals in the arts and sciences (MTE, 2010). For this group, we also include middle-level managers, as defined by Ribas, Sampaio and Trevisan (2024). The low-skilled group comprises all other occupations, excluding military and law enforcement personnel and public officials. As a robustness check, we further divide the low-skilled group into middle-skilled workers, which include skilled technicians and low-level managers, and other low-skilled workers.

The main outcome in our analysis is wages, calculated as the contractual salary divided by hours worked. Another outcome is employment, measured as the sum of full-time equivalent workers per municipality. In addition to these variables, we also examine the probability of resignation, defined as an employee-initiated departure or retirement, the probability of layoff, defined as an employer-initiated termination, and the number of new arrivals, defined as the sum of full-time equivalent workers appearing in a municipality for the first time.

For each year, the sample is restricted to workers aged 25 to 60 who hold a regular employment contract as of December 31. Workers employed by the government and those in the mining or agricultural sectors are excluded. Accordingly, our sample consists of nonfarm workers in the private sector. To minimize noise from measurement errors, we further restrict the sample to individuals who are observed for three or more years in RAIS. These sample restrictions are similar to the ones applied by Gerard et al. (2021).

3.5 Descriptive Statistics

Table 1 presents summary statistics by treatment status for municipality and worker characteristics in 2014, prior to the dam failure in Mariana. In our baseline sample, which includes municipalities within 60 km of a large tailings dam, there are 209 treated and 362 untreated municipalities. The total number of workers per group is roughly 1.2 million. Panel A shows that the composition of the economic sectors and the educational levels in downstream and upstream municipalities were similar. However, downstream municipalities were significantly larger in terms of population and employment and exhibited higher GDP per capita, longer life expectancy, and more expensive housing. Still, differences in employment growth and GDP growth in 2014 were statistically insignificant.

[Table 1 about here]

Panel B presents the characteristics of workers in our sample, restricting their location to municipalities in panel A. It indicates that the wages of high- and low-skilled workers were about 10% higher in downstream municipalities than upstream. The rates of resignations, layoffs, and new arrivals in the municipality were very similar between treated and untreated groups, but the shares of high-skilled workers and workers with tertiary education were 2 percentage points (p.p.) higher downstream. The share of male and white workers was similar, but workers downstream were slightly older and had longer tenure. Finally, the average number of regular employees per establishment and the average number of establishments per municipality were larger downstream.

4 Empirical Strategy

To estimate the indirect effects of environmental disasters occurring elsewhere, we employ a diff-in-disc design (Grembi, Nannicini and Troiano, 2016). In this design, the treated group corresponds to workers in municipalities located downstream of a large tailings dam that have not been physically damaged by actual dam failures. The untreated group corresponds to workers in upstream municipalities close to the same dams, which are not exposed to the risk of a dam failure.

Let W_{ijt} be the wage of worker i employed in municipality j in year t, D_j be the treatment dummy, equal to 1 if municipality j is downstream and 0 otherwise, and h_j be the shortest Euclidean distance of municipality j to a large tailings dam.[11] Considering that the environmental disaster occurs in year 0, we estimate the following diff-in-disc model:

$$\log W_{ijt} = \sum_{\tau \neq -1} \left[\gamma_\tau \left(D_j \cdot \mathbb{1}[t=\tau] \right) + \eta_{1,\tau} \left(h_j \cdot \mathbb{1}[t=\tau] \right) + \eta_{2,\tau} \left(h_j \cdot D_j \cdot \mathbb{1}[t=\tau] \right) \right] \\ + \eta_3' Z_i + \mu_j + \theta_t + \varepsilon_{ijt} \tag{5}$$

where $\mathbb{1}[t=\tau]$ is a dummy indicating observations in a given year τ, Z_i is a vector of worker characteristics, including age, gender, race, and education, μ_j represents the municipality fixed effect, θ_t represents the year-specific effect, and ε_{ijt} is a random term. In this model, we do not include time-varying covariates to avoid problems with "bad" controls (Caetano et al., 2024; Roth et al., 2023). Since our diff-in-disc is not staggered, the two-way fixed effects (TWFE) regression form is equivalent to alternative estimators (Roth et al., 2023).

In equation (5), our coefficient of interest is γ_τ, which represents the local average treatment effect (LATE) on workers employed in municipalities very close to a large tailings dam. This coefficient varies over time to capture short- and long-term effects, with year -1 serving as the reference. In our estimates, year 0 corresponds to 2015, the year of the first disaster in Mariana, while year 4 corresponds to 2019, the year of the second disaster in Brumadinho. As a result, the coefficient γ_4 captures two overlapping effects that cannot be disentangled: the long-term effect of the first incident and the effect of the second incident. To check for the presence of pre-trends in the dependent variable, we also

[11] For treated municipalities, h_j corresponds to the shortest distance to a large upstream dam.

estimate the coefficients for years prior the first disaster (i.e., $\tau < -1$).

To account for the time-varying impacts of activities related to tailings dams, we include the second interaction term in equation (5), $\left(h_j \cdot \mathbb{1}[t = \tau]\right)$. This term, along with the third interaction term, $\left(h_j \cdot D_j \cdot \mathbb{1}[t = \tau]\right)$, also ensures that the LATE is identified by comparing municipalities that are very close to a tailings dam and hence to each other. Instead of restricting the analysis to a few neighboring municipalities around each tailings dam, the linear parameterization of the distance gradient allows us to expand the radius (or the bandwidth), increasing the sample size. This strategy is similar to a conventional regression discontinuity design with a rectangular kernel weighting (Hahn, Todd and Van der Klaauw, 2001; Imbens and Lemieux, 2008). For robustness, we estimate our model using various bandwidths ranging from 60 km to 90 km.

The estimation of equation (5) is weighted by the number of full-time equivalent workers. For each worker in our sample, their weight corresponds to their hours worked per week divided by 40. The same TWFE regression is applied to estimate the effects on the probabilities of resignation and layoff. For employment levels, firm size, the number of new workers entering the local market, and the number of firms, the diff-in-disc is estimated using a log-linear Poisson regression with municipality fixed effects (Cohn, Liu and Wardlaw, 2022; Chen and Roth, 2023). Except for the number of firms, these variables refer to the full-time equivalent number of workers (Alvarez et al., 2018). In all regressions, standard errors are clustered at the municipality level (Bertrand, Duflo and Mullainathan, 2004; Abadie et al., 2022).

Due to the proximity between treated and untreated municipalities, the untreated group may also be indirectly affected through changes in the spatial equilibrium. In the potential outcome framework, this would constitute a violation of the stable unit treatment value assumption (SUTVA). According to Hudgens and Halloran (2008), when SUTVA is violated, the treatment effect is the sum of the direct effect, which is the difference between treated and untreated units under the new equilibrium, and the indirect effect, which arises from the difference between untreated outcomes in the new and old equilibria. Since we aim to explore how differences in risk perception result in wage differentials, we focus on comparing municipalities under the same spatial equilibrium. Rather than adhering to the potential outcome framework, this approach aligns with the decision-analytic framework from Dawid (2000, 2015), which focuses solely on Hudgens and Halloran's direct effect and does not require SUTVA to hold.

5 Results

This section contains the results from our diff-in-disc estimations, and it is organized as follows. First, we present and discuss the estimated effects on the wages of high- and low-skilled workers. Second, we analyze the estimated effects on employment levels and resignations. Finally, we examine the implied demand elasticities for different subgroups of high-skilled workers and the relationship between changes in WTA and labor supply elasticities.

5.1 Effect on Wages

Below, we discuss the estimated effects on wages in three parts. The first part presents the average effects for each skill group. The second part examines the relationship of the effects on high-skilled workers with firm size and job tenure. The third part analyzes the heterogeneity across different subgroups of high-skilled workers. Results for subgroups of low-skilled workers and several robustness checks are available in the Online Appendix.

5.1.1 Effect on Wages by Skill Level

Figure 3 presents the results of the diff-in-disc estimations for log wages. The three graphs in panel (a) are based on municipalities close to large dams, and the graphs in panel (b) comprise municipalities close to high-damage dams. In each panel, the graphs on the left-hand side show the average effects for all workers, those in the middle show the effects for high-skilled workers, and those on the right-hand side show the effects for low-skilled workers. Each graph exhibits the diff-in-disc estimates and corresponding confidence intervals using four different bandwidths: 60km, 70km, 80km, and 90km. For the same dams, the diff-in-disc compares the changes in the treated municipalities, located downstream, with the changes in the untreated municipalities, located upstream, before and after 2014 (time -1).

[Figure 3 about here]

The results for all workers in panels (a) and (b) indicate that, before the first incident in 2015 (time 0), changes in discontinuities between treated and untreated municipalities are small and mostly insignificant. After the first incident, we do not observe significant increases in wages, except through year four in panel (a). Following the second incident in 2019 (time 4), wages increased by 1.9% to 2.7% more in municipalities below large dams than in those above the same dams. However, this effect is insignificant when the sample is restricted to areas close to high-damage dams, in panel (b).

As we split the workers into high- and low-skilled groups, a clear distinction emerges. Among high-skilled workers, in the middle graph of panel (a), wages increased by 2.7% to 4.9% more downstream than upstream two years after the first incident. In year four, the estimated effect ranges between 6.6% and 9.8%. Considering that the median high-skilled worker in municipalities with a large dam earned about $28,046 (2023 PPP) in 2014, this effect represents an increase of $1,851 to $2,749 in the annual cost per worker.

In contrast, the right-hand graph in panel (a) shows that the effects on the wages of low-skilled workers are smaller and mostly insignificant, reaching up to 2.1% in year four. According to our conceptual framework, there are two possible explanations for the distinct effects between skill groups. The first is the difference in mobility costs or dispersion, which could be larger in the low-skilled group. The second is the difference in skill substitutability, which could be higher in tasks performed by low-skilled workers.

Another explanation is that high- and low-skilled workers respond differently to information shocks based on their education. However, this explanation is not consistent with the supplementary results included in the Online Appendix. These results indicate that the effect on the wages of workers with tertiary education is generally weaker than the effect on the wages of high-skilled workers (Figure S4, Online Appendix). The weaker relationship between the effects on wages and education is due to the fact that the wages of high-skilled workers without a college degree also increased. Moreover, among low-skilled workers, the effect on wages is not positively correlated with education (Figure S5, Online Appendix). As a robustness check, we also separate the low-skilled group into middle-skilled workers, including skilled technicians and low-level managers, and other low-skilled workers. For both subgroups, the effects on wages are small and almost always insignificant (Figure S6, Online Appendix).

Using the more restrictive sample of municipalities adjacent to high-damage dams, panel (b) of Figure 3 displays slightly smaller effects on the wages of high-skilled workers, ranging from 2.3% to 3.6% in year two and from 4.7% to 6.7% in year four. Yet, the distinct impacts between skill groups remain evident, with smaller and insignificant effects in the low-skilled group. We also estimate the effects in municipalities close to moderate-to-high damage dams and close to any tailings dam (Figure S3, Online Appendix). These estimates are consistent with, but slightly smaller than, those in panel (a) of Figure 3. The larger and more significant effects around large dams suggest that workers are not so sensitive to the risk assessment reported by regulatory officials or the presence of tailings dams of any size. They seem rather more sensitive to large tailings dams, which are more noticeable to the naked eye. For the sake of space, we henceforth focus our analysis on municipalities close to large dams and briefly discuss the effects on areas close to high-damage dams as a robustness check.[12]

It is worth stressing that the estimated effects result from the comparison between downstream and nearby upstream municipalities, and changes in one area may affect the

[12]Results for areas close to moderate-high damage dams and any tailings dam are available upon request.

outcomes in other areas. Indeed, compared to a random group of untreated municipalities, we find that the wages of high-skilled workers in upstream municipalities declined after the first disaster (Figure S7, Online Appendix). Thus, our main findings should not be interpreted as the total causal effect in a potential outcome framework because they do not take changes in the general equilibrium into consideration (Heckman, Lochner and Taber, 1998; Hudgens and Halloran, 2008). As we compare the downstream municipalities with a random sample from the untreated ones, this total effect is found to be significant but smaller (Figure S7, Online Appendix).[13]

5.1.2 Effect on Wages by Firm Size and Job Tenure

In panel (a) of Figure 4, high-skilled workers are split based on the number of regular employees in their current business establishment. In establishments with fewer than 100 employees, the impact on wages is small and mostly insignificant. The positive impact on wages appears to come from larger establishments, with 100 employees or more. In year two, the wages of high-skilled workers increased by 3.7% to 6.8% in these establishments, whereas in year four wages increased by 13% to 16%. According to our theoretical framework, this result indicates that either substitutability between skills decreases with firm size or smaller firms provide better amenities to their employees, or both.

[Figure 4 about here]

In panel (b) of Figure 4, we separate high-skilled workers based on their current job tenure. To facilitate our analysis, we refer to those employed for less than 24 months as short-term workers, those employed between 24 and 48 months as medium-term workers, and those employed for more than 48 months as long-term workers. Although the effect on wages is noisier for short-term workers, it also looks slightly larger than the effect for long-term workers. One year after the first disaster, their wages increased by 2.9%-5.9%,

[13] This estimated effect tends to be more biased because the random group of untreated municipalities is not as similar to treated municipalities as the upstream municipalities close to tailings dams.

while the wages of other workers showed almost no increase. As these workers increase their tenure, the effect on medium-term workers becomes larger and significant, ranging from 7.2% to 11% in years two and three. Still, through year three, the effect on long-term workers is small and insignificant. In year four, though, this effect becomes close to 9%. This result suggests that the average effect on wages increases over time in part because short-term workers hired with higher wages gradually replace older workers.

Another implication of the heterogeneity by tenure is that, after a shift in risk perception, short-term workers are better able to negotiate higher wages than long-term workers. This is in line with the notion that workers' mobility costs increase with tenure (Burdett, 1978), reducing their bargaining power. Aligned with this hypothesis, supplementary results confirm that short-term workers increase their probability of resignation after a disaster elsewhere, while the effects on medium- and long-term workers are small and insignificant (Figure S8, Online Appendix).

For robustness, we also estimate the effect on wages by firm size and job tenure in municipalities near high-damage dams (Figure S9, Online Appendix) and the effect on the wages of low-skilled workers by firm size and job tenure (Figure S10, Online Appendix). In areas close to high-damage dams, the effect on the wages of high-skilled workers is smaller and less often significant, but the heterogeneity with respect to firm size and job tenure is consistent with the patterns shown in Figure 4. Among low-skilled workers, the effects are small and insignificant, except for the effects on medium-term workers, which varies between 2% and 4.6% from years two to four.

5.1.3 Effect on Wages by Race, Gender and Sub-Occupation

In this part, we examine the effect on the wages of high-skilled workers, separating them by race, gender, and subtype of occupation. As regards race, we refer to Black and Indigenous peoples as non-white and the other races, including Asians, as white. Panel (a) of Figure 5 shows that wages increased more for white workers than non-white workers. Through year four, the effect on the wages of white high-skilled workers is between 6.9% and 9.8%, whereas the effect for non-white workers ranges between 3.7% and 5.5%. Regarding the differences between genders, panel (b) reveals that the effect is slightly higher for men than for women. In year four, the effect on the wages of male high-skilled workers varies from 7.5% to 10.6%, whereas the effect for female workers is estimated to be between 5% and 7.7%.

[Figure 5 about here]

Panel (c) of Figure 5 displays the effect on the wages of high-skilled workers, splitting them between managerial and non-managerial positions. For managerial positions, the estimated effects vary considerably across bandwidths. Under a large bandwidth (i.e., 90km), this effect is not greater than the effect for non-managerial positions. However, under a small bandwidth (i.e., 60km), the estimated effect for managerial positions is considerably larger. In years two and three, the estimates are around 7%, whereas the effect for non-managerial positions ranges between 4% and 5%. In year four, the effect for non-managerial positions is about 8%, while the effect for managerial positions is estimated to be as high as 12%. Considering that smaller bandwidths yield broader confidence intervals but less biased estimates (Lee and Lemieux, 2010), it seems safe to say that salaries in managerial positions are more sensitive to the information shock caused by a disaster.

Overall, these heterogeneous effects may result from differences in mobility costs across subgroups or in skill substitutability in their tasks. The estimated effects on employment will confirm which explanation is more likely to occur. Results for municipalities near high-damage dams and for low-skilled workers are available in the Online Appendix (Figures S11 and S12, respectively). Once again, the effects in areas near high-damage dams are overall smaller, but the differences are in line with those in Figure 5. For low-skilled workers, the effects on subgroups of workers are small and often insignificant.

5.2 Effect on Employment

There are two broad explanations for the observed wage increase among high-skilled workers. It might be caused by a demand shock in labor markets downstream, which would also be followed by a rise in high-skilled employment. Considering the type of natural experiment we examine, though, a more plausible explanation is that wages rise due to a negative supply shock — i.e., workers require higher salaries to work and live in municipalities at risk. This supply shock should, if anything, reduce the employment levels in downstream municipalities. However, the effect is expected to be heterogeneous depending on workers' mobility costs and skill substitutability in tasks performed by specific groups of workers and firms.

5.2.1 Effect on Employment and Resignations by Skill Level

In Figure 6, panels (a) and (b) present the effects on the number of workers employed in the municipality and the probability of workers resigning from their current job or retiring, respectively. The left-hand graph of panel (a) shows that overall employment in treated municipalities did not change significantly after the first disaster. Neither did the average establishment size (Figure S13, Online Appendix). However, the left-hand graph of panel (b) reveals an increasing probability of resignation. Although the estimates are sensitive to the bandwidth, we observe that the effect is as high as 1.6 p.p. (or 52% compared to the baseline probability) in year four. The increase in resignations does not necessarily imply declining employment because workers could be switching jobs within municipalities. Still, the result in panel (b) corroborates the negative supply shock.

[Figure 6 about here]

As we separate employment by skill level, the middle graph of panel (a) shows a declining number of high-skilled workers employed in treated municipalities. Through year four, this number decreased by 6% to 10%. The estimated effects, however, are noisy and, therefore, not significantly different from zero. Later we argue that part of the noise is due to considerable heterogeneity across firms and workers. In areas close to high-damage dams, the estimates are similar but more often significant (Figure S14, Online Appendix).

For low-skilled workers, in the right-hand graph of panel (a), the effects on employment are close to zero. These effects remain insignificant even when we split the low-skilled group into middle-skilled and other low-skilled workers (Figure S15, Online Appendix), by firm size (Figure S16, Online Appendix), or by worker characteristics (Figure S17, Online Appendix). These findings suggest that either low-skilled workers do not update their risk perception after a disaster or their mobility costs are too high to alter their wage and employment levels.

Despite the different effects for high- and low-skilled workers in panel (a), the middle and right-hand graphs in panel (b) show that the increasing probability of resignation is similar between these groups. Moreover, we find analogous results when we focus on areas near high-damage dams, with more significant effects for low-skilled labor (Figure S14, Online Appendix). These results point out that both types of workers are more willing to quit their jobs after observing an environmental disaster elsewhere. Nevertheless, the lack of change in wage and employment levels suggests that low-skilled workers are very dispersed (or attached to their current location), making their supply inelastic. This evidence is in line with the low migration rates after natural disasters in Brazil (Alves, Ehrl and Lima, 2025).

To confirm that local markets faced a negative supply shock, we also estimate the effects on the probability of workers being laid off (Figure S18, Online Appendix). Results confirm that the effects on both skill groups are small, often insignificant, and, if anything, negative in the short run. Another result that supports the negative supply shock is the significant reduction in the arrival of new workers in downstream municipalities (Figure S19, Online Appendix), suggesting that not only current local workers update their risk perception but also potential new entrants.

5.2.2 Heterogeneous Effects on High-Skilled Employment

To understand the heterogeneous responses to the rising cost of high-skilled labor, we estimate the effect on high-skilled employment by establishment size and subgroup of workers. For the sake of space, the graphs with year-specific effects are available in the Online Appendix.

Our results show that the reduction in high-skilled employment occurred mostly in small establishments, which have between 20 and 100 regular employees, declining by 14% to 18% in year four. Micro establishments, with fewer than 20 workers, also present significant reductions, ranging from 5.5% to 7% in year four. In large establishments, with 100 employees or more, the effect is small and insignificant (Figure S20, Online Appendix).

After splitting high-skilled workers by individual characteristics, we find that the employment reduction is small and insignificant for men, white workers, more educated workers, and managers, suggesting a very inelastic demand for these subgroups. For female, non-white, less educated, and non-managerial high-skilled workers, we observe a reduction ranging between 7% and 19% in year four, which is two to three times larger than the reduction for their counterparts (Figure S22, Online Appendix). Additional results also indicate that the effect on resignations is larger for female, non-white, and non-managerial workers (Figure S23, Online Appendix).

5.3 Demand and Supply Elasticities and Willingness to Accept

In this part, we use the estimated effects on wages and employment levels to calculate the implied demand elasticities for different subgroups of high-skilled workers. The effects on wages and employment are also used to infer the relationship between supply elasticity and changes in WTA for each subgroup. For this relationship, the considerable variation across subgroups allows us to obtain the minimum increase in WTA and the maximum supply elasticity for the overall group of high-skilled workers.

For low-skilled workers, this analysis cannot be performed, as neither the effect on wages nor the effect on employment is statistically significant. On the one hand, the small effects on low-skilled workers imply that their labor supply is inelastic, at least at the municipal level. On the other hand, they also imply that the demand elasticity for high-skilled workers can be calculated by simply dividing the effect on employment by the effect on wages.

5.3.1 Implied Demand Elasticities

The first two columns of Table 2 present the estimated effects on wages and employment for all high-skilled workers and subgroups four years after the first disaster. These estimates are obtained using the sample of municipalities close to large tailings dams and the bandwidths generally producing the most significant results — i.e., 60km for wages and 90km for employment.[14] The third column calculates the implied demand elasticity in year four, assuming that the subgroups of high-skilled workers are perfect substitutes. According to equation (2), if low-skilled employment does not change — i.e., $d\log E(L) = 0$ —, then the ratio between $d\log E(H)$ and $d\log W(H)$ is directly related to the elasticity of substitution between high- and low-skilled workers, $1/(1-\delta_a)$. This elasticity may vary depending on the tasks performed by each subgroup of high-skilled workers.

[Table 2 about here]

The results indicate that demand is more elastic for non-white workers than for white workers, for women than for men, and for less educated workers than for more educated workers. These findings suggest that female, non-white, and less educated workers tend to be employed in tasks with a higher elasticity of substitution between skills. If this elasticity is inversely related to the comparative advantage of high-skilled workers across tasks, then the observed differences between subgroups is consistent with discriminatory differences in productivity (Aigner and Cain, 1977; Hurst, Rubinstein and Shimizu, 2024).

[14] Using less significant effects on employment would imply more inelastic demand for all subgroups, while less significant effects on wages would lead to noisier elasticities.

The third column of Table 2 also shows that the demand for non-managerial workers is more elastic than for managers, indicating that managerial skills are more essential than other skills. With respect to employer size, small establishments present the highest demand elasticity, while large establishments have the lowest. According to our monopsony model, this means that skill substitution is less likely to occur in larger establishments. Thus, these firms tend to retain their employees by covering the higher cost of high-skilled labor. For micro establishments, the effects on wages and employment are both small, suggesting that their labor supply is inelastic.

5.3.2 Relationship Between Supply Elasticity and Willingness to Accept

With the estimated effects on wages and employment, we also calculate the implied relationship between supply elasticity and increase in WTA, which is equal to the reduction in the value of local amenities. For this calculation, we apply the following textbook formula:

$$\varepsilon_S(x) = \frac{d\log E(x)}{d\log W(x) - |d\log G|}$$

where $\varepsilon_S(x)$ is the supply elasticity for group x, $d\log E(x)$ and $d\log W(x)$ are the estimated effects on employment and wages, respectively, and $|d\log G|$ is the reduction in the value of local amenities after a disaster elsewhere.

Figure 7 presents the implied relationship between $\varepsilon_S(x)$ and $d\log G$, separated by subgroups. In all graphs, the thick black line serves as a reference, representing the relationship for all high-skilled workers. In the top-right graph, we observe that non-white workers have either a more elastic labor supply or a more sensitive amenity valuation, or both, compared to white workers. Likewise, the other graphs show that female, less educated, and non-managerial workers exhibit a more elastic labor supply or more sensitive amenity valuation than male, more educated, and managerial workers, respectively. These findings indicate that the subgroups of high-skilled workers with more elastic demand are also more prone to move away from areas with increased risk perception.

[Figure 7 about here]

However, this pattern does not hold when comparing workers employed by firms of different sizes. Although larger establishments exhibit a more inelastic demand for high-skilled labor, they also encounter a more elastic supply. In contrast, micro establishments appear to face an inelastic labor supply, suggesting that their high-skilled workers endure higher mobility costs. This inelastic supply does not seem to be related to firm-specific amenities in micro establishments because these firms also present the highest effect on resignations (Figure S20, Online Appendix).

Next, we use the implied curves for different subgroups of high-skilled workers to identify possible values for labor supply elasticity and the change in amenity value, or WTA. To be consistent, these values must lie on a section of the overall curve (the thick black line) where at least one subgroup's curve is above it, and another subgroup's curve is below it. As highlighted by the dashed lines in Figure 7, this condition is met only if the labor supply elasticity is at most 1.2 and the increase in WTA is at least 17%. If the rise of WTA were slightly below 17%, then both managerial and non-managerial workers, as well as more and less educated workers, would exhibit lower supply elasticity than the average worker.

Considering the median annual salary of $28,046 (2023 PPP) for a high-skilled worker in 2014, a 17% increase in WTA represents $4,768 PPP per year for each worker. Based on the VSL of $13 million, calculated by Kearsley (2024) for values of 2023, this WTA is equivalent to the perceived risk of one additional death per 2,727 individuals.

6 Conclusion

This study examines the indirect impact of a preventable environmental disaster in Brazil on labor markets, providing new insights into how risk perception affects wages and employment. Using a diff-in-disc design and matched employer-employee data, we find a clear distinction between high- and low-skilled workers in response to heightened mistrust over safety measures for tailings dams. After observing the potential damages of a dam collapse, high-skilled workers demand higher wages or relocate to a safer area, whereas low-skilled workers are constrained by mobility costs, leading to limited changes in their employment conditions. These findings underscore the critical role of mobility constraints and bargaining power in determining workers' compensation for environmental risks.

Our results also reveal significant heterogeneity within the high-skilled group. Female, non-white, and non-managerial workers receive lower compensation for increased risks than their male, white, and managerial counterparts. These disparities point to the compounded challenges faced by disadvantaged groups in labor markets. However, given their higher propensity to relocate, these subgroups still appear in a better position than long-term workers in general, whose wages and resignation rates seem unresponsive to environmental risks. Another determinant of labor market impacts relates to firm size. While larger establishments show a more inelastic demand for high-skilled labor, raising salaries without reducing employment, smaller establishments bear the brunt of employment adjustments. Nevertheless, employment in micro establishments is less affected than in other firms because their high-skilled workers also appear to endure high mobility costs.

Overall, our findings highlight the broader implications of environmental risks for labor market inequality and public policy. With workers facing mobility constraints, valuations of environmental quality can be difficult to estimate. As a result, policies that strengthen regulatory frameworks to mitigate environmental risks should be more equitable than those improving transparency, which depend on workers' ability to move freely. More broadly, the rising risks of natural disasters in many regions of the globe may result in unequal compensation across skill groups, emphasizing the need for policies that facilitate the mobility of more vulnerable workers.

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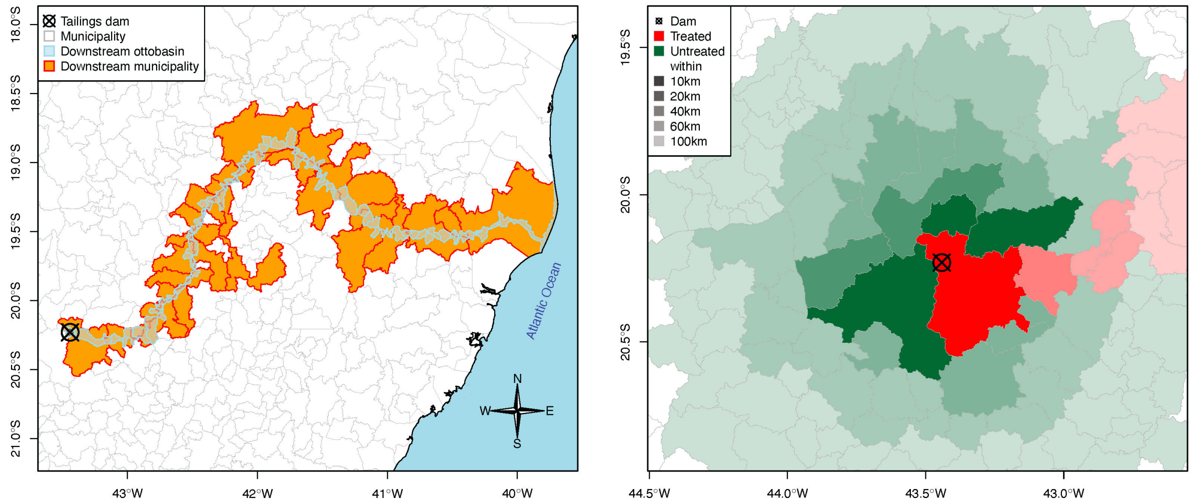
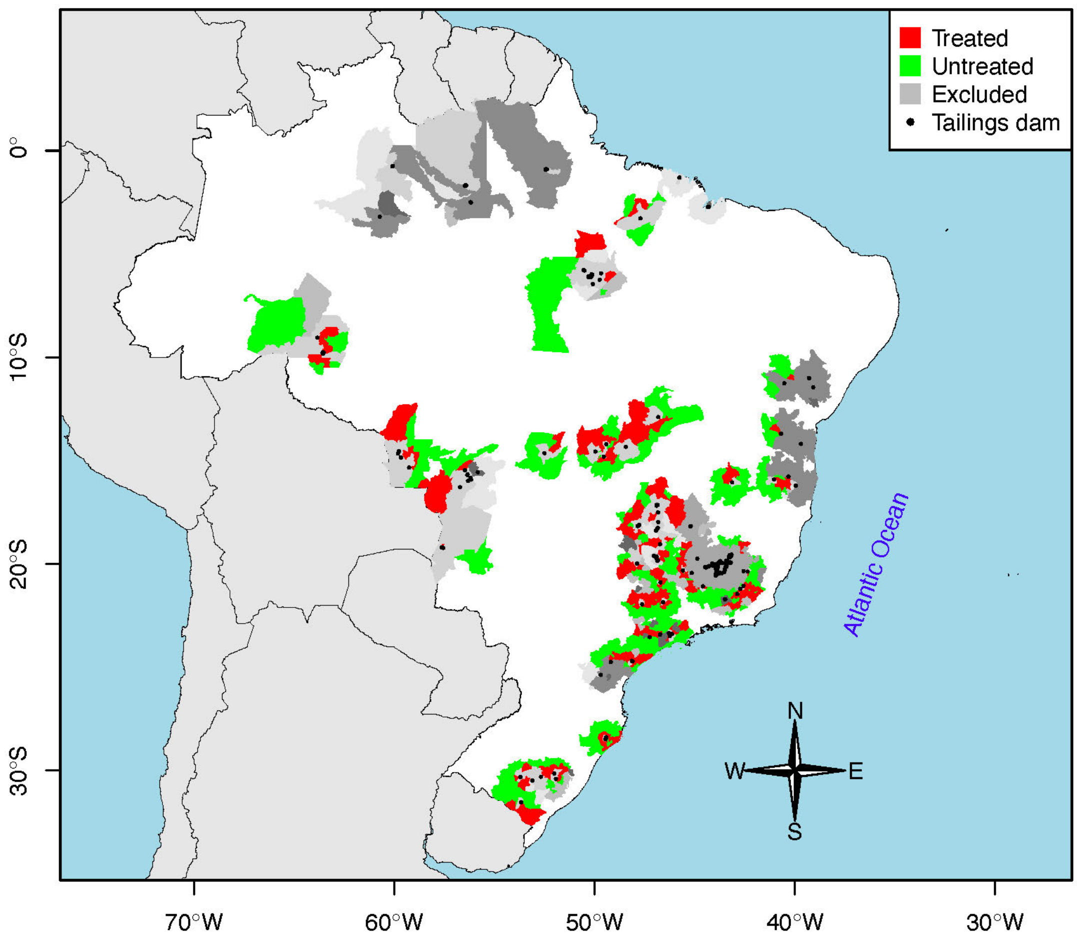
Figure 1: Treated (Downstream) and Untreated Municipalities

(a) Downstream Basins **(b)** Treated and Untreated Municipalities



This figure presents two maps showing the location of the *Nova Barragem de Santarém*, a tailings dam in Mariana, MG. The map on the left-hand side shows the level 6 hydrographic basins forming the watercourse originated at the dam, as well as the municipalities it serves. The map on the right-hand side shows municipalities close to the dam, separated into treated (downstream) and untreated (upstream).

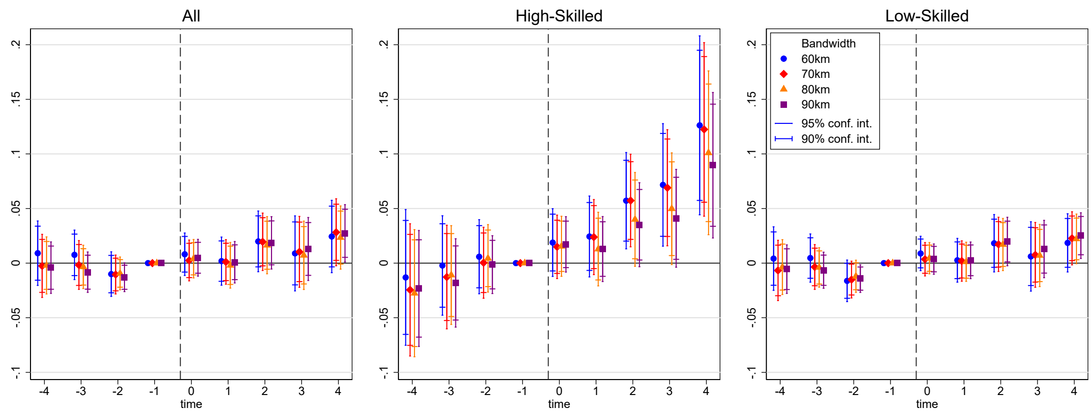
Figure 2: Sample of Municipalities and the Location of Large Tailings Dams



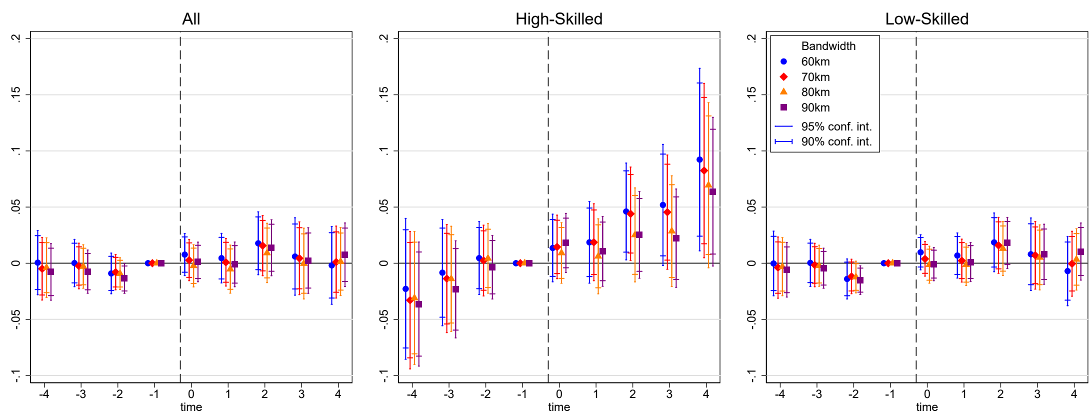
This map shows the 'treated' municipalities, located downstream, and 'untreated' municipalities, located upstream, within 75 km of a large tailings dam. 'Excluded' municipalities are those directly affected by dam failures, with a large tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam.

Figure 3: Estimated Effects on Wages by Skill Level

(a) Large Dam Areas



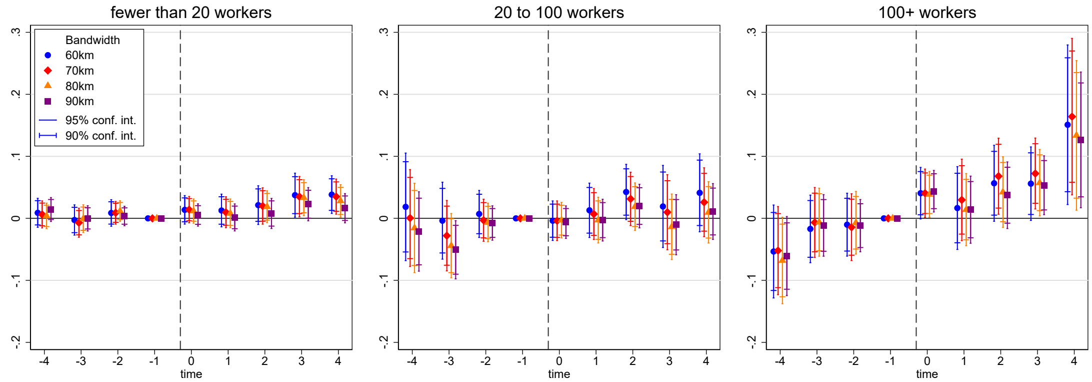
(b) High-Damage Dam Areas



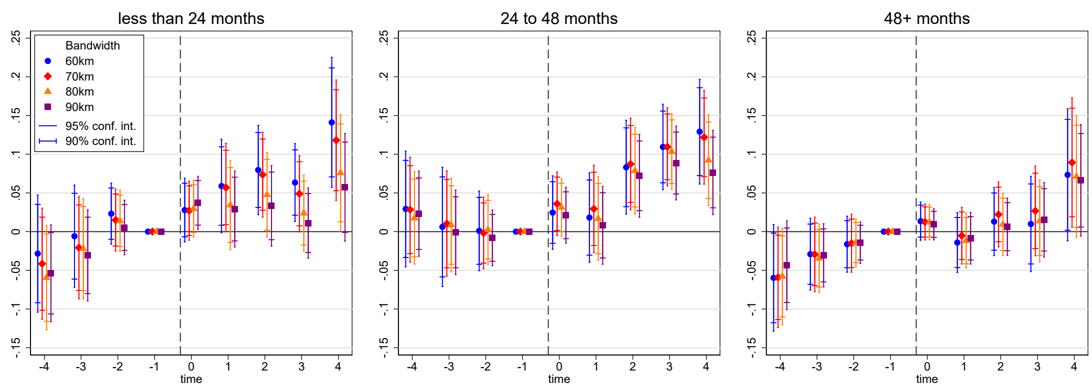
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the log of hourly wages on December 31 of each year. Based on the shortest distance to a dam, the diff-in-disc is estimated using four different bandwidths. The sample in panel (a) includes municipalities within the radius of a large tailings dam. Panel (b) only considers municipalities close to a high-damage dam. In both panels, we exclude municipalities directly affected by dam failures, with a large or high-damage tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The left-hand graphs include all workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Among these workers, the middle and right-hand graphs consider only those in high- and low-skilled occupations, respectively. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure 4: Estimated Effects on the Wages of High-Skilled Workers by Firm Size and Job Tenure

(a) By Firm Size



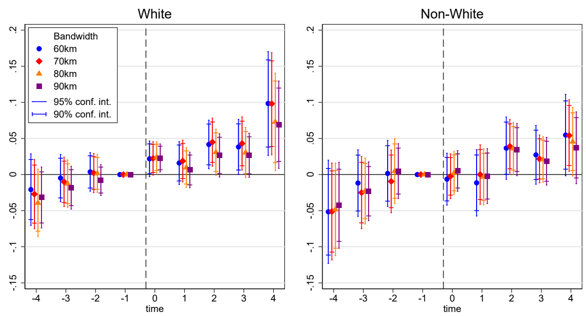
(b) By Job Tenure



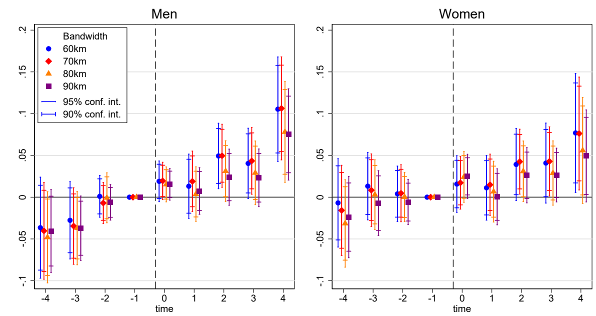
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a large tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the log of hourly wages on December 31 of each year. Based on the shortest distance to a large tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a large tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all high-skilled workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Panel (a) separates high-skilled workers based on the number of regular, full-time equivalent employees in their current business establishment. Panel (b) separates high-skilled workers based on their current job tenure. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure 5: Estimated Effects on the Wages of High-Skilled Workers by Race, Gender, and Sub-Occupation

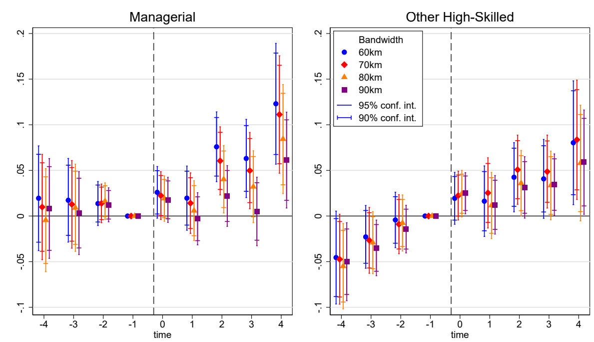
(a) By Race



(b) By Gender



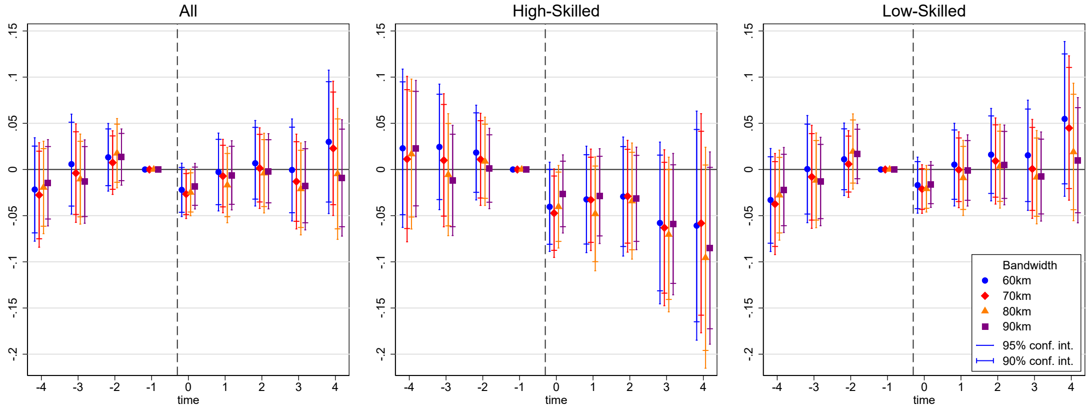
(c) By Sub-Occupation



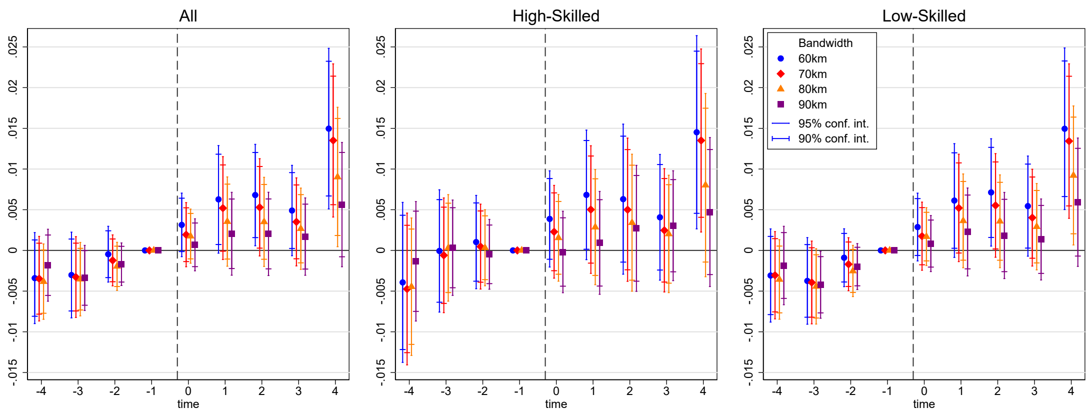
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a large tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the log of hourly wages on December 31 of each year. Based on the shortest distance to a large tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a large tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all high-skilled workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Panel (a) separates high-skilled workers based on race. Dark-skinned and indigenous workers are referred to as 'non-white,' and the other workers, including Asians, are referred to as 'white.' Panel (b) separates high-skilled workers based on gender at birth. Panel (c) separates high-skilled workers based on whether they occupy a managerial position or not. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure 6: Estimated Effects on Employment and Resignations by Skill Level

(a) Number of Employed Workers (in log)

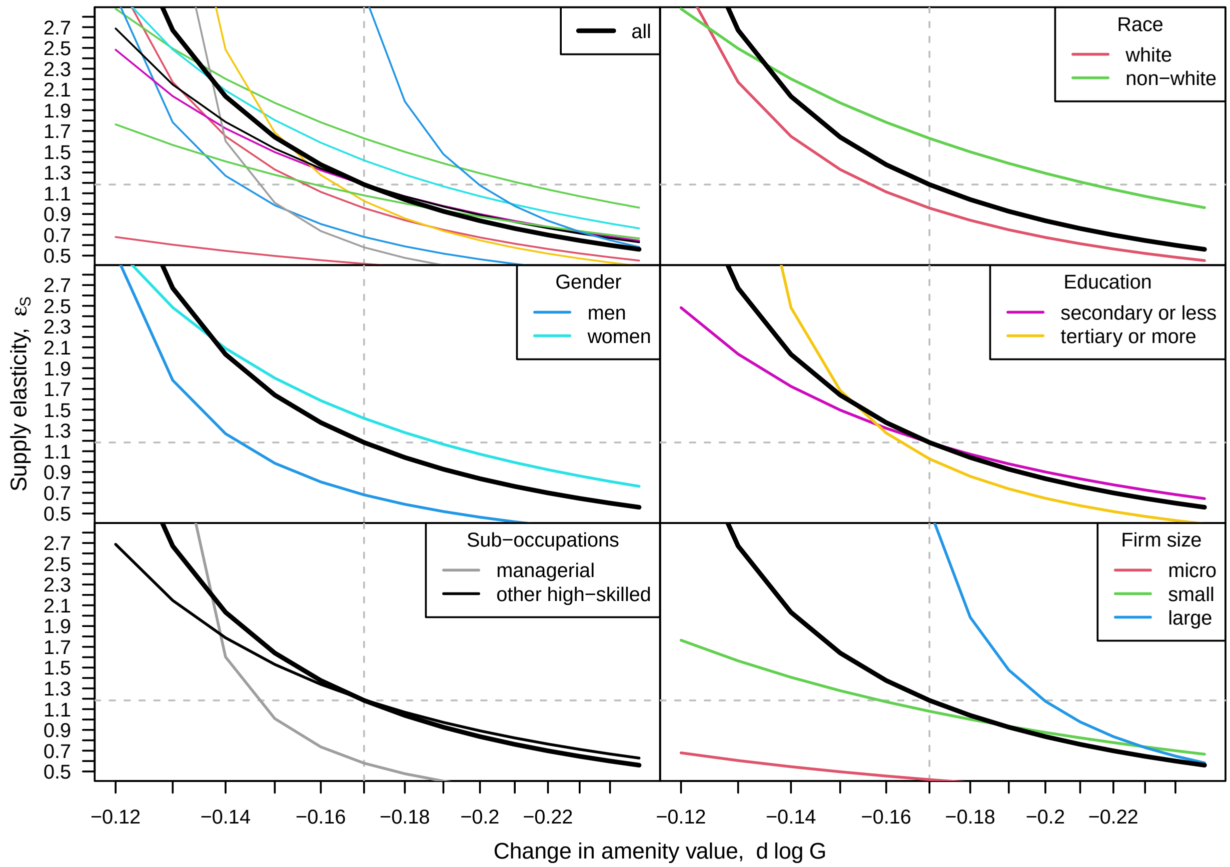


(b) Probability of Resignation



This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing treated municipalities, located downstream of a large tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. Based on the shortest distance to a large tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a large tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The left-hand graphs consider all workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Among these workers, the middle and right-hand graphs consider only those in high- and low-skilled occupations, respectively. In panel (a), the dependent variable is the number of full-time equivalent workers regularly employed in the municipality on December 31 of each year. For this variable, the diff-in-disc is estimated using log-linear Poisson regressions with municipality fixed-effects and a dummy for each year. In panel (b), the dependent variable is equal to one if the worker resigns or retires from their job in which they have been regularly employed since December 31 of the previous year and zero otherwise. For this variable, The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure 7: Implied Relationship Between Labor Supply Elasticity and Change in Amenity Value for Subgroups of High-Skilled Workers



This figure illustrates the implied relationship between labor supply elasticity (ε_S) and change in the value of amenities ($d \log G$) for different subgroups of high-skilled workers. The relationship is drawn from the estimates presented in Table 2. For all high-skilled workers, the dashed lines indicate the maximum supply elasticity and the minimum change in amenity values that is consistent with the comparison between the average relationship (thick black line) and the relationships for each pair of subgroups. For race, 'non-white' refers to dark-skinned and indigenous workers, and 'white' refers to the other workers, including Asians. For firm size, 'micro' establishments are defined as those with fewer than 20 regular, full-time equivalent employees, 'small' establishments have 20 to 100, and 'large' establishments have more than 100.

Table 1: Descriptive Statistics by Treatment Status in 2014

	Treated (Downstream)		Untreated (Upstream)		Difference	
Panel A: Municipalities						
distance to a dam (km)	24.7	(1.20)	35.8	(0.78)	-11.0***	(1.37)
log population	9.79	(0.09)	9.36	(0.06)	0.43***	(0.11)
log housing rent	5.33	(0.02)	5.28	(0.02)	0.05*	(0.03)
log employment	7.00	(0.14)	6.29	(0.10)	0.70***	(0.17)
employment growth (%)	6.62	(2.12)	5.79	(0.88)	0.83	(1.99)
log GDP per capita	7.61	(0.04)	7.42	(0.03)	0.19***	(0.05)
GDP growth (%)	10.1	(0.92)	10.9	(0.73)	-0.79	(1.19)
% services in GDP	52.8	(1.18)	51.2	(0.82)	1.56	(1.40)
% employment in extraction	7.48	(0.76)	6.35	(0.59)	1.13	(0.97)
% employment in manufacturing	21.0	(1.22)	22.9	(1.09)	-1.86	(1.71)
% employment in services	68.5	(1.39)	67.4	(1.18)	1.10	(1.88)
% employment in agriculture	3.03	(0.61)	3.42	(0.48)	-0.38	(0.78)
life expectancy	75.1	(0.12)	74.7	(0.10)	0.46***	(0.16)
years of schooling	9.67	(0.07)	9.56	(0.05)	0.11	(0.08)
Panel B: Workers						
log wage	2.02	(0.02)	1.91	(0.01)	0.11***	(0.02)
log wage, high-skilled	2.43	(0.03)	2.33	(0.02)	0.10***	(0.03)
log wage, low-skilled	1.92	(0.02)	1.84	(0.01)	0.09***	(0.02)
rate of resignations	0.03	(0.00)	0.03	(0.00)	0.00	(0.00)
rate of layoffs	0.16	(0.01)	0.15	(0.00)	0.01	(0.01)
rate of new arrivals	0.21	(0.01)	0.21	(0.00)	0.00	(0.01)
share of high-skilled	0.18	(0.01)	0.15	(0.00)	0.02***	(0.01)
share of managers	0.05	(0.00)	0.05	(0.00)	-0.00	(0.00)
share with secondary education	0.57	(0.01)	0.56	(0.01)	0.02	(0.01)
share with tertiary education	0.15	(0.01)	0.13	(0.00)	0.02**	(0.01)
share of male	0.58	(0.01)	0.57	(0.01)	0.01	(0.01)
share of white	0.70	(0.02)	0.73	(0.01)	-0.03	(0.02)
tenure (months)	53.2	(1.43)	49.4	(0.85)	3.80**	(1.56)
age	37.6	(0.11)	37.0	(0.09)	0.62***	(0.14)
number of establishments	539.4	(63.5)	339.9	(43.2)	199.5***	(74.6)
employment per establishment	122.0	(12.7)	83.2	(8.93)	38.8**	(15.2)
N. of municipalities	209		362			
N. of workers	1,219,924		1,182,128			

This table presents the sample means for municipal characteristics, in Panel A, and worker characteristics, in Panel B, with standard errors in parentheses. The sample is split into treated observations, located downstream of a large tailings dam, and untreated, located upstream. The last two columns present the difference between these groups, with standard errors clustered at the municipality level in parentheses. ***, **, * represent statistical significance at the 1%, 5% and 10% levels, respectively. Sample restrictions in Panel A are described in Sections 3.2 and 3.3. Sample restrictions in Panel B are described in Section 3.4. In addition, only municipalities within 60 km of a large tailings dam are considered.

Table 2: Estimated Effects on Wages and Employment and Implied Labor Demand Elasticity for Subgroups of High-Skilled Workers

	Estimated Effect on		Demand
	Wages	Employment	elasticity
All	0.098 (0.032)	-0.085 (0.053)	-0.867
Race			
white	0.098 (0.037)	-0.069 (0.055)	-0.696
non-white	0.055 (0.029)	-0.188 (0.083)	-3.433
Gender			
men	0.105 (0.032)	-0.044 (0.063)	-0.417
women	0.077 (0.036)	-0.132 (0.058)	-1.715
Education			
secondary or less	0.075 (0.027)	-0.113 (0.049)	-1.516
tertiary or more	0.119 (0.040)	-0.052 (0.067)	-0.441
Sub-occupation			
managerial	0.123 (0.034)	-0.027 (0.041)	-0.221
other high-skilled	0.080 (0.035)	-0.107 (0.063)	-1.329
Firm size			
micro	0.038 (0.015)	-0.055 (0.030)	-1.450
small	0.041 (0.032)	-0.139 (0.051)	-3.382
large	0.151 (0.065)	-0.058 (0.096)	-0.382

This table presents the diff-in-disc estimates for the effects on wages and employment levels for different subgroups of high-skilled workers. Robust standard errors, clustered at the municipality level, are reported in parentheses. Estimates are obtained from regressions using the sample of municipalities close to large tailings dams. For the effect on wages, we apply a bandwidth of 60 km. For the effect on employment, we apply a bandwidth of 90 km. The last column presents the labor demand elasticity, calculated as the ratio between the effects on employment and wages. For race, 'non-white' refers to dark-skinned and indigenous workers, and 'white' refers to the other workers, including Asians. For firm size, 'micro' establishments are defined as those with fewer than 20 regular, full-time equivalent employees, 'small' establishments have 20 to 100, and 'large' establishments have more than 100.

A Model Solutions

A.1 Labor Demand Curves

From (1), the inverse labor supply function for firm j is:

$$W_j(x) = \left[\lambda_x^{-1} N_j(x)\right]^{\beta_x} G_j^{-1}, \tag{A1}$$

for $x = \{H, L\}$. Then, as described in the main text, firm j's problem is the following:

$$\max_{\{E_j(H), E_j(L), K_j\}} A_j \left[\mathbf{E}_j(a)\right]^{1-\alpha} K_j^{\alpha} - W_j(H)E_j(H) + W_j(L)E_j(L) + rK_j \tag{A2a}$$

$$\text{s.t. } \mathbf{E}_j(a) = \left(\theta_H(a)\left[E_j(H)\right]^{\delta_a} + \theta_L(a)\left[E_j(L)\right]^{\delta_a}\right)^{1/\delta_a} \tag{A2b}$$

$$\text{and } W_j(x) = \left[\lambda_x^{-1} E_j(x)\right]^{\beta_x} G_j^{-1} \qquad \text{for } x = \{H, L\}, \tag{A2c}$$

where r is the price of capital, assumed to be exogenous.

We plug (A2b) into (A2a) and derive the first order conditions with respect to $E_j(x)$ and K_j:

$$(1+\beta_x)\, W_j(x) = (1-\alpha)\theta_x(a)\left[E_j(x)\right]^{\delta_a - 1}\left[\mathbf{E}_j(a)\right]^{-\delta_a} Y_j, \text{ and}$$

$$r = \alpha K_j^{-1} Y_j.$$

Taking the log on both sides of these equations, we have

$$\begin{aligned} \log W_j(x) =\ & \log(1-\alpha) + \log\theta_x(a) - \log(1+\beta_x) - (1-\delta_a)\log E_j(x) \\ & - \delta_a \log \mathbf{E}_j(a) + \log Y_j \qquad\qquad \text{for } x \in \{H, L\}, \text{ and} \\ \log r =\ & \log\alpha - \log K_j + \log Y_j; \end{aligned}$$

and totally differentiating these two equations, we obtain

$$d\log W_j(x) = -(1-\delta_a)d\log E_j(x) - \delta_a d\log \mathbf{E}_j(a) + d\log Y_j \quad \text{for } x \in \{H, L\}, \text{ and} \tag{A3}$$

$$d\log Y_j = d\log K_j. \tag{A4}$$

Placing (A3) into (A4), we have

$$d\log W_j(x) = -(1-\delta_a)d\log E_j(x) - \delta_a d\log \mathbf{E}_j(a) + d\log K_j, \tag{A5}$$

for $x \in \{H, L\}$.

By totally differentiating the production function and (A2b), we know that

$$d\log Y_j = (1-\alpha)d\log \mathbf{E}_j(a) + \alpha d\log K_j \tag{A6}$$

and

$$d\log \mathbf{E}_j(a) = \begin{cases} s_H(a)d\log E_j(H) + s_L(a)d\log E_j(L) & \text{if } \delta_a > -\infty, \\ d\log E_j(H) = d\log E_j(L) & \text{if } \delta_a \to -\infty, \end{cases} \tag{A7}$$

where

$$s_H(a) = \frac{\theta_H(a)\left[E_j(H)\right]^{\delta_a}}{\theta_H(a)\left[E_j(H)\right]^{\delta_a} + \theta_L(a)\left[E_j(L)\right]^{\delta_a}}, \text{ and}$$
$$s_L(a) = \frac{\theta_L(a)\left[E_j(L)\right]^{\delta_a}}{\theta_H(a)\left[E_j(H)\right]^{\delta_a} + \theta_L(a)\left[E_j(L)\right]^{\delta_a}}.$$

Plugging (A4) into (A6), we have that, in the long run,

$$d\log K_j = d\log \mathbf{E}_j(a) \tag{A8}$$

for any δ_a. Then, plugging (A7) into (A5) we have the **long-run skill-specific labor demand curve**:

$$\begin{cases} d\log W_j(x) = (1-\delta_a)s_{x'}(a)\left[d\log E_j(x') - d\log E_j(x)\right] & \text{if } \delta_a > -\infty, \\ d\log E_j(x) = d\log E_j(x') & \text{if } \delta_a \to -\infty, \end{cases} \tag{A9}$$

with $x, x' \in \{H, L\}$ and $x \neq x'$.

In the short run, we consider that $d\log K_j = 0$ in (A6). Then, plugging (A6) into (A3), we obtain the **short-run skill-specific labor demand curve**:

$$\begin{cases} d\log W_j(x) = -\left[\alpha s_x(a) + s_{x'}(1-\delta_a)\right]d\log E_j(x) & \\ \qquad\qquad + (1-\delta_a-\alpha)\, s_{x'}(a)d\log E_j(x') & \text{if } \delta_a > -\infty, \\ d\log E_j(x) = d\log E_j(x') & \text{if } \delta_a \to -\infty, \end{cases} \tag{A10}$$

with $x, x' \in \{H, L\}$ and $x \neq x'$.

A.2 Shares of High- and Low-Skill Contribution

From the FOC, we know that

$$\frac{(1+\beta_H)\, W_j(H)}{(1+\beta_L)\, W_j(L)} = \frac{\theta_H(a)}{\theta_L(a)} \left[\frac{E_j(H)}{E_j(L)}\right]^{\delta_a - 1}.$$

With (A2c), it becomes

$$\frac{\left[E_j(H)\right]^{1-\delta_a+\beta_H}}{\left[E_j(L)\right]^{1-\delta_a+\beta_L}} = \frac{\lambda_H^{\beta_H}}{(1+\beta_H)} \frac{(1+\beta_L)}{\lambda_L^{\beta_L}} \frac{\theta_H(a)}{\theta_L(a)}.$$

If $\beta_L \geq \beta_H$, then

$$\left[\Omega_{LH}\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1}{1-\delta_a+\beta_H}} \geq \frac{E_j(H)}{E_j(L)} \geq \left[\Omega_{LH}\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1}{1-\delta_a+\beta_L}}, \tag{A11}$$

where

$$\Omega_{LH} = \frac{\lambda_H^{\beta_H}}{(1+\beta_H)} \frac{(1+\beta_L)}{\lambda_L^{\beta_L}}.$$

This implies that

$$\begin{aligned}
\Omega_{LH}^{\frac{\delta_a}{1-\delta_a+\beta_H}} \left[\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1+\beta_H}{1-\delta_a+\beta_H}} &\geq \frac{\theta_H(a)}{\theta_L(a)} \left[\frac{E_j(H)}{E_j(L)}\right]^{\delta_a} \geq \Omega_{LH}^{\frac{\delta_a}{1-\delta_a+\beta_L}} \left[\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1+\beta_L}{1-\delta_a+\beta_L}} \quad \text{if } \delta_a \geq 0, \\
\Omega_{LH}^{\frac{\delta_a}{1-\delta_a+\beta_H}} \left[\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1+\beta_H}{1-\delta_a+\beta_H}} &\leq \frac{\theta_H(a)}{\theta_L(a)} \left[\frac{E_j(H)}{E_j(L)}\right]^{\delta_a} \leq \Omega_{LH}^{\frac{\delta_a}{1-\delta_a+\beta_L}} \left[\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1+\beta_L}{1-\delta_a+\beta_L}} \quad \text{if } \delta_a < 0.
\end{aligned} \tag{A12}$$

The share of low-skilled contribution to labor can be rewritten as:

$$s_L(a) = \frac{1}{1 + \frac{\theta_H(a)}{\theta_L(a)} \left[\frac{E_j(H)}{E_j(L)}\right]^{\delta_a}}.$$

Then, with (A12), we know that

$$\begin{aligned}
\left(1+\Omega_{LH}^{\frac{\delta_a}{1-\delta_a+\beta_L}} \left[\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1+\beta_L}{1-\delta_a+\beta_L}}\right)^{-1} &\geq s_L(a) \geq \left(1+\Omega_{LH}^{\frac{\delta_a}{1-\delta_a+\beta_H}} \left[\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1+\beta_H}{1-\delta_a+\beta_H}}\right)^{-1} \quad \text{if } \delta_a > 0, \\
s_L(a) &= \frac{\theta_L(a)}{\theta_L(a)+\theta_H(a)} \quad \text{if } \delta_a = 0, \\
\left(1+\Omega_{LH}^{\frac{\delta_a}{1-\delta_a+\beta_H}} \left[\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1+\beta_H}{1-\delta_a+\beta_H}}\right)^{-1} &\geq s_L(a) \geq \left(1+\Omega_{LH}^{\frac{\delta_a}{1-\delta_a+\beta_L}} \left[\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1+\beta_L}{1-\delta_a+\beta_L}}\right)^{-1} \quad \text{if } \delta_a < 0.
\end{aligned} \tag{A13}$$

Under the assumptions that $\beta_L \gg \beta_H$ and $\lambda_L > 1$, these inequalities lead to three lemmas describing the behavior of $s_L(a)$ and $s_H(a)$.

Lemma A1. $s_H(a) \to 0$ *if and only if one of the following conditions holds:*

1. $\theta_H(a) \to 0$ and $\delta_a > -\infty$.

2. $\beta_L \to \infty$ and $\delta_a > 0$.

Moreover, if $\beta_H \to 0$ and $\delta_a \to 1$, then $s_H(a)$ converges faster to zero as $\theta_H(a)$ decreases or β_L increases.

Lemma A2. *$s_L(a) \to 0$ if and only if $\theta_L(a) \to 0$ and $\delta_a > -\infty$.*

Lemma A3. *Assume that $\theta_L(a)/\theta_H(a)$ is continuously differentiable and strictly decreasing in a. If $\beta_L \to \infty$ and $\delta'(a) \leq 0$, then $E_j(H)/E_j(L)$ and $s_H(a)$ strictly increase with a.*

A.3 Elasticities to Amenities in the Long Run

By totally differentiating (A2c), we have

$$d \log W_j(x) = \beta_x d \log E_j(x) - d \log G_j, \tag{A14}$$

for $x \in \{H, L\}$. Then, plugging (A14) into (A9), we obtain:

$$d \log E_j(H) = \begin{cases} \frac{d \log G_j + (1-\delta_a) s_L(a) d \log E_j(L)}{\beta_H + (1-\delta_a) s_L(a)} & \text{if } \delta_a > -\infty \\ 0 & \text{if } \delta_a \to -\infty, \end{cases}$$

and

$$d \log E_j(L) = \begin{cases} \frac{d \log G_j + (1-\delta_a) s_H(a) d \log E_j(H)}{\beta_L + (1-\delta_a) s_H(a)} & \text{if } \delta_a > -\infty \\ 0 & \text{if } \delta_a \to -\infty. \end{cases}$$

Notice that, for $\delta_a \to -\infty$, (A9) implies that $d \log E_j(H) = d \log E_j(L)$. Since $\beta_L > \beta_H$, the only solution in (A14) that allows $d \log E_j(H) = d \log E_j(L)$ is $d \log W_j(x) = -d \log G_j$ with $x \in \{H, L\}$. This implies that $d \log E_j(H) = d \log E_j(L) = 0$.

Solving these equations for $d \log E_j(H)$ and $d \log E_j(L)$ gives the **long-run elasticities of employment** to amenities:

$$\frac{d \log E_j}{d \log G_j}(x, a) = \begin{cases} \frac{1}{\beta_x + s_{x'}(a) \frac{(1-\delta_a)\left(\beta_{x'} - \beta_x\right)}{1 - \delta_a + \beta_{x'}}} & \text{if } \delta_a > -\infty \\ 0 & \text{if } \delta_a \to -\infty, \end{cases} \tag{A15}$$

for $x \in \{H, L\}$ and $x' \neq x$.

By replacing (A15) in (A14), we obtain the **long-run elasticities of wages**:

$$\frac{d \log W_j}{d \log G_j}(x,a) = \begin{cases} -\frac{s_{x'}(a)(1-\delta_a)\left(\beta_{x'}-\beta_x\right)}{\beta_x\left(1-\delta_a+\beta_{x'}\right)+s_{x'}(a)(1-\delta_a)\left(\beta_{x'}-\beta_x\right)} & \text{if } \delta_a > -\infty \\ -1 & \text{if } \delta_a \to -\infty, \end{cases} \tag{A16}$$

for $x \in \{H, L\}$ and $x' \neq x$.

A.4 Behavior of Long-Run Elasticities

In (A15), the sensitivity of employment to amenities is non-negative for any $x \in \{H, L\}$ because $s_{x'}(a) \in (0,1)$, $\delta_a \leq 1$, and hence

$$\frac{d \log E_j}{d \log G_j}(x,a) = \frac{1}{\beta_x + s_{x'}(a)\frac{(1-\delta_a)\left(\beta_{x'}-\beta_x\right)}{1-\delta_a+\beta_{x'}}} > 0.$$

However, in (A16), the sign of the elasticity of wages is different for low- and high-skilled workers because

$$\frac{d \log W_j}{d \log G_j}(x,a) = -\frac{s_{x'}\left(1-\delta_a\right)\left(\beta_{x'}-\beta_x\right)}{\beta_x\left(1-\delta_a+\beta_{x'}\right)+s_{x'}\left(1-\delta_a\right)\left(\beta_{x'}-\beta_x\right)} \begin{cases} \geq 0 & \text{if } \beta_x > \beta_{x'}, \text{ and} \\ \leq 0 & \text{if } \beta_x < \beta_{x'}, \end{cases}$$

for $x \in \{H, L\}$ and $x \neq x'$. Under the assumption that $\beta_L > \beta_H$, the increasing risk of an environmental disaster should, if anything, increase the wages of high-skilled workers and reduce the wages of low-skilled workers, as long as $\delta_a > -\infty$.

Following a negative shock in the value of amenities, $d \log G_j < 0$, we verify the conditions for three different scenarios for each skill $x \in \{H, L\}$:

a. Wages and employment do not change;

b. Employment declines, but wages are rigid;

c. Wages change, but employment does not.

Lemma A4. *Assume that $\beta_L \gg \beta_H$. In the long run, scenario a. occurs for skill L only if $\beta_L \to \infty$. Moreover, if $\beta_L \to \infty$, a sufficient condition for scenario a. is $\delta_a > 0$.*

Lemma A5. *Assume that $\beta_L \gg \beta_H$. In the long run, scenario b. occurs for skill x, with $x \in \{H, L\}$, only if $\beta_x < \infty$ and $\delta_a > -\infty$. In addition to these necessary conditions, scenario b. occurs if and only if $\delta_a = 1$ or $\theta_x(a) \to 1$. Finally, if a subgroup of skill x is observed in scenario a., we should not observe another subgroup of skill x in scenario b.*

Lemma A6. *In the long run, scenario c. occurs for skill x, with $x \in \{H, L\}$, only if $\delta_a \to -\infty$ or $\beta_x \to \infty$. Moreover, $\delta_a \to -\infty$ is also a sufficient condition for scenario c. If scenario c. occurs and $\delta_a > -\infty$, then wages should decline. If scenario c. occurs and $\beta_x < \infty$, then $d \log W_j(x, a) = -d \log G_j > 0$.*

A.5 Elasticities to Amenities in the Short Run

For the short run, plugging (A14) into (A10) we obtain

$$d \log E_j(H) = \begin{cases} \frac{d \log G_j + (1-\delta_a-\alpha) s_L(a) d \log E_j(L)}{\beta_H + \alpha s_H(a) + (1-\delta_a) s_L(a)} & \text{if } \delta_a > -\infty \\ \frac{d \log G_j}{\beta_H + \alpha} & \text{if } \delta_a \to -\infty, \end{cases}$$

and

$$d \log E_j(L) = \begin{cases} \frac{d \log G_j + (1-\delta_a-\alpha) s_H(a) d \log E_j(H)}{\beta_L + \alpha s_L(a) + (1-\delta_a) s_H(a)} & \text{if } \delta_a > -\infty \\ \frac{d \log G_j}{\beta_L + \alpha} & \text{if } \delta_a \to -\infty. \end{cases}$$

which solving for $d \log E_j(H)$ and $d \log E_j(L)$ gives the **short-run elasticities of employment** to amenities:

$$\frac{d \log E_j}{d \log G_j}(x, a) = \begin{cases} \frac{1}{\beta_x + \alpha + s_{x'}(a) \frac{(1-\delta_a-\alpha)\left(\beta_{x'} - \beta_x\right)}{1-\delta_a+\beta_{x'}}} & \text{if } \delta_a > -\infty \\ \frac{1}{\beta_x + \alpha} & \text{if } \delta_a \to -\infty, \end{cases} \tag{A17}$$

for $x \in \{H, L\}$ and $x' \neq x$.

By replacing (A17) in (A14), we obtain the **short-run elasticities of wages**:

$$\frac{d \log W_j}{d \log G_j}(x, a) = \begin{cases} -\frac{\alpha + s_{x'}(a) \frac{(1-\delta_a-\alpha)\left(\beta_{x'} - \beta_x\right)}{1-\delta_a+\beta_{x'}}}{\beta_x + \alpha + s_{x'}(a) \frac{(1-\delta_a-\alpha)\left(\beta_{x'} - \beta_x\right)}{1-\delta_a+\beta_{x'}}} & \text{if } \delta_a > -\infty \\ -\frac{\alpha}{\beta_x + \alpha} & \text{if } \delta_a \to -\infty, \end{cases} \tag{A18}$$

for $x \in \{H, L\}$ and $x' \neq x$.

A.6 Behavior of Short-Run Elasticities

In the short run, the elasticity of employment to amenities is always non-negative,

$$\frac{d\log E_j}{d\log G_j}(x,a) = \begin{cases} \frac{1}{\beta_x+\alpha+s_{x'}(a)\frac{(1-\delta_a-\alpha)\left(\beta_{x'}-\beta_x\right)}{1-\delta_a+\beta_{x'}}} & > 0 \quad \text{if } \delta_a > -\infty \\ \frac{1}{\beta_x+\alpha} & > 0 \quad \text{if } \delta_a \to -\infty, \end{cases}$$

for $x \in \{H, L\}$ and $x' \neq x$, because

$$\beta_x + \alpha + s_{x'}(a)\frac{(1-\delta_a-\alpha)\left(\beta_{x'}-\beta_x\right)}{1-\delta_a+\beta_{x'}} = (1-\delta_a+\beta_{x'})^{-1}\Big\{\beta_x\beta_{x'} + (1-\delta_a)\left[s_x(a)\beta_x + s_{x'}(a)\beta_{x'}\right]$$
$$+\alpha\left[s_{x'}(a)\beta_x + s_x(a)\beta_{x'} + 1 - \delta_a\right]\Big\} \quad > 0, \text{ and}$$
$$\beta_x + \alpha > 0,$$

with $\beta_x \geq 0$, $\delta_a \leq 1$, and $s_x(a), s_K(a) \in (0, 1)$.

Assuming that $\beta_L > \beta_H$, the short-run elasticity of high-skilled workers' wages is non-positive,

$$\frac{d\log W_j}{d\log G_j}(H,a) = \begin{cases} -\left[\alpha + s_L(a)\frac{(1-\delta_a-\alpha)(\beta_L-\beta_H)}{1-\delta_a+\beta_L}\right]\frac{d\log E_j(H,a)}{d\log G_j} & < 0 \quad \text{if } \delta_a > -\infty \\ -\alpha\frac{d\log E_j(H,a)}{d\log G_j} & < 0 \quad \text{if } \delta_a \to -\infty, \end{cases}$$

because

$$\alpha + s_L(a)\frac{(1-\delta_a-\alpha)(\beta_L-\beta_H)}{1-\delta_a+\beta_L}$$
$$= \frac{(1-\delta_a)s_L(a)(\beta_L-\beta_H)+\alpha\left[s_L(a)\beta_H+s_H(a)\beta_L+1-\delta_a\right]}{1-\delta_a+\beta_L} > 0,$$

$\frac{d\log E_j(H,a)}{d\log G_j} > 0$, $\alpha \in (0, 1)$, and $\delta_a \leq 1$. However, the short-run elasticity of wages for low-skilled workers can be positive if δ_a is finite but less than one and the difference between β_L and β_H is large enough. Moreover, the greater the output elasticity of labor (i.e., $\alpha \to 0$), the more likely it is that the elasticity of low-skill wages is positive. Otherwise, this elasticity is also non-positive in the short run.

Following a negative shock in the value of amenities, $d\log G_j < 0$, we verify again the conditions for three different scenarios for each skill $x \in \{H, L\}$:

a. Wages and employment do not change;

b. Employment declines, but wages are rigid;

c. Wages change, but employment does not.

Lemma A7. *Assume that* $\beta_L \gg \beta_H$*. In the short run, scenario a. occurs for skill L only if* $\beta_L \to \infty$*. Moreover, if* $\beta_L \to \infty$*, a sufficient condition for scenario a. is that either* $\delta_a > 0$ *or* $\delta_a \to -\infty$*.*

Lemma A8. *Assume that* $\beta_L \gg \beta_H$ *and* $\alpha > 0$*. In the short run, scenario b. occurs for skill* x*, with* $x \in \{H, L\}$*, only if* $\beta_x < \infty$ *and* $\delta_a = 1$*. In addition to these necessary conditions, scenario b. occurs if and only if* $\beta_{x'} \to 0$ *and* $\theta_x \to 1$ *with* $x' \neq x$*. Finally, if a subgroup of* x *is observed in scenario a., we should not observe another subgroup of* x *in scenario b.*

Lemma A9. *In the short run, scenario c. occurs for skill* x*, with* $x \in \{H, L\}$ *if and only if* $\beta_x \to \infty$ *and* $\delta_a \in (-\infty, 0)$*. Moreover, if scenario c. occurs, then* $d \log W_j(x, a) < 0$*.*

A.7 Proof of Lemmas

Proof of Lemma A1.

Since $s_H(a) = 1 - s_L(a)$, we must show the sufficient condition for the lower bound of $s_L(a)$ to converge to one and the necessary condition for the upper bound of $s_L(a)$ to converge to one. As demonstrated below, these conditions are the same.

According to (A13), both the upper and lower bounds of $s_L(a)$ will approach one if

$$\Omega_{LH}^{\frac{\delta_a}{1-\delta_a+\beta_x}} \left[\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1+\beta_x}{1-\delta_a+\beta_x}} \to 0$$

for all $x \in \{H, L\}$. But for any $x \in \{H, L\}$, this is only possible if one of the following conditions holds:

1. $\theta_H(a) \to 0$ and $\frac{1+\beta_x}{1-\delta_a+\beta_x} > 0$.

2. $\Omega_{LH} \to 0$ and $\frac{\delta_a}{1-\delta_a+\beta_x} > 0$.

3. $\Omega_{LH} \to \infty$ and $\frac{\delta_a}{1-\delta_a+\beta_x} < 0$.

Since $\lambda_L > 1$ and $\beta_H < \infty$, Ω_{LH} is always finite, so condition 3. cannot be satisfied. If $\theta_H(a) \to 0$, the first condition is violated if and only if $\delta_a \to -\infty$. If $\Omega_{LH} \to 0$, the second condition is violated if and only if $\delta_a < 0$. Moreover, since $\lambda_L > 1$, $\Omega_{LH} \to 0$ if and only if $\beta_L \to \infty$.

Then, we can rewrite conditions 1. and 2., as follows:

1. $\theta_H(a) \to 0$ and $\delta_a > -\infty$.

2. $\beta_L \to \infty$ and $\delta_a > 0$.

If either of these conditions holds, the lower bound of $s_L(a)$ will converge to one. Moreover, the upper bound of $s_L(a)$ will converge to one only if either condition holds.

Regarding the speed of convergence, if $\beta_H \to 0$ and $\delta_a \to 1$, the lower bound of $s_L(a)$ will converge faster to one as $\theta_H(a)$ decreases or β_L increases. The reason is that

$$\lim_{\beta_H \to 0, \delta_a \to 1} \frac{\delta_a}{1-\delta_a+\beta_H} \to \infty, \text{ and } \lim_{\beta_H \to 0, \delta_a \to 1} \frac{1+\beta_H}{1-\delta_a+\beta_H} \to \infty.$$

With very large exponents in (A13), the lower bound of $s_L(a)$ converges quickly to one if $\Omega_{LH} < \theta_L(a)/\theta_H(a)$ and either $\Omega_{LH} < 1$ or $\theta_H(a) < 0.5$. As $\theta_H(a)$ decreases or β_L increases, this condition is more likely to be satisfied. □

Proof of Lemma A2.

According to (A13), the upper and lower bounds of $s_L(a)$ will approach zero if

$$\Omega_{LH}^{\frac{\delta_a}{1-\delta_a+\beta_x}} \left[\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1+\beta_x}{1-\delta_a+\beta_x}} \to \infty$$

for all $x \in \{H, L\}$. But for any $x \in \{H, L\}$, this is only possible if one of the following conditions holds:

1. $\theta_L(a) \to 0$ and $\frac{1+\beta_x}{1-\delta_a+\beta_x} > 0$.

2. $\Omega_{LH} \to 0$ and $\frac{\delta_a}{1-\delta_a+\beta_x} \to -1$.

3. $\Omega_{LH} \to \infty$ and $\frac{\delta_a}{1-\delta_a+\beta_x} > 0$.

Since $\lambda_L > 1$ and $\beta_H < \infty$, Ω_{LH} is always finite, so condition 3. cannot be satisfied. For condition 2., $\frac{\delta_a}{1-\delta_a+\beta_x} \to -1$ if and only if $\delta_a \to -\infty$. In this case, though, $s_L(a)$ is not defined. For condition 1., the exponent will be greater than zero if δ_a is finite.

Then, we can ignore conditions 2. and 3. and rewrite condition 1. as follows:

1. $\theta_L(a) \to 0$ and $\delta_a > -\infty$.

If this condition holds, the upper bound of $s_L(a)$ will converge to zero. Moreover, the lower bound of $s_L(a)$ will converge to zero only if this condition holds. $\square$

Proof of Lemma A3.

From (A11), we take the first derivative of the lower and upper bounds with respect to a. For $x \in \{H, L\}$,

$$\frac{d}{da}\left(\left[\Omega_{LH}\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1}{1-\delta_a+\beta_x}}\right) = \left[\Omega_{LH}\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1}{1-\delta_a+\beta_x}} \left\{\frac{\delta'_a}{(1-\delta_a+\beta_x)^2}\log\left[\Omega_{LH}\frac{\theta_H(a)}{\theta_L(a)}\right]\right.$$
$$\left. + \frac{1}{1-\delta_a+\beta_x}\Theta'_{HL}(a)\left[\frac{\theta_H(a)}{\theta_L(a)}\right]^{-1}\right\}$$

where $\Theta'_{HL}(a) = \frac{d}{da}\left[\frac{\theta_H(a)}{\theta_L(a)}\right]$ and $\delta'_a = \frac{d\delta(a)}{da}$. By assumption, $\Theta'_{HL}(a) > 0$, which implies that

$$\frac{d}{da}\left(\left[\Omega_{LH}\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1}{1-\delta_a+\beta_x}}\right) > 0$$

if $\delta'_a \le 0$ and $\Omega_{LH} \le \theta_L(a)/\theta_H(a)$.

Since $\lambda_L > 1$, $\Omega_{LH} \to 0$ if and only if $\beta_L \to \infty$. In other words, if $\beta_L \to \infty$, then $\Omega_{LH} \le \theta_L(a)/\theta_H(a)$ for nearly any a. Therefore, if $\beta_L \to \infty$ and $\delta'(a) < 0$, then both the lower and upper bounds of $E_j(H)/E_j(L)$ will strictly decrease with a.

From (A13), we also take the first derivative of the lower and upper bounds with respect to a. First, let

$$\tilde{s}_L(a;x) \equiv \left(1 + \Omega_{LH}^{\frac{\delta_a}{1-\delta_a+\beta_x}} \left[\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1+\beta_x}{1-\delta_a+\beta_x}}\right)^{-1},$$

which represents either the lower bound or the upper bound of $s_L(a)$ depending on whether $x = L$ or $x = H$. Differentiating it with respect to a, we obtain:

$$\frac{d\tilde{s}_L(a;x)}{da} = -\left[\tilde{s}_L(a;x)\right]^2 \Omega_{LH}^{\frac{\delta_a}{1-\delta_a+\beta_x}} \frac{1+\beta_x}{1-\delta_a+\beta_x} \left\{ \left[\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{\delta_a}{1-\delta_a+\beta_x}} \Theta'_{HL}(a) \right.$$
$$\left. + \left[\frac{\theta_H(a)}{\theta_L(a)}\right]^{\frac{1+\beta_x}{1-\delta_a+\beta_x}} \frac{\delta'_a}{1-\delta_a+\beta_x} \log\left[\Omega_{LH}\frac{\theta_H(a)}{\theta_L(a)}\right] \right\}.$$

By assumption, $\Theta'_{HL}(a) > 0$. This implies that $d\tilde{s}_L(a;x)/da < 0$ if $\delta'_a \leq 0$ and $\Omega_{LH} \leq \theta_L(a)/\theta_H(a)$. Again, if $\beta_L \to \infty$, then $\Omega_{LH} \leq \theta_L(a)/\theta_H(a)$ for nearly any a.

Therefore, if $\beta_L \to \infty$ and $\delta'(a) \leq 0$, then both the lower and upper bounds of $s_L(a)$ will strictly decrease with a, while the lower and upper bounds of $s_H(a)$ will strictly increase with a. □

Proof of Lemma A4.

From (A15), $d\log E_j(L,a) = 0$ if and only if one of the following conditions hold:

1. $\beta_L + s_H(a)\frac{(1-\delta_a)(\beta_H-\beta_L)}{1-\delta_a+\beta_H} \to \infty$ and $\delta_a > -\infty$.
2. $\delta_a \to -\infty$.

Condition 1. holds if and only if $\beta_L \to \infty$. Thus, $d\log E_j(L,a) = 0$ if and only if

1. $\beta_L \to \infty$, or
2. $\delta_a \to -\infty$,

or both.

Suppose that δ_a is finite. From (A16), we have that

$$\lim_{\beta_L\to\infty} \frac{d\log W_j(L,a)}{d\log G_j} = -\lim_{\beta_L\to\infty} \frac{s_H(a)\,(1-\delta_a)\,(\beta_H-\beta_L)}{\beta_L\,(1-\delta_a+\beta_H) + s_H(a)\,(1-\delta_a)\,(\beta_H-\beta_L)}$$
$$= \frac{s_H(a)\,(1-\delta_a)}{\beta_H + s_L(a)\,(1-\delta_a)},$$

which equals zero if $s_H(a) = 0$ or $\delta_a = 1$. From Lemma A1, $s_H(a) = 0$ if $\beta_L \to \infty$ and $\delta_a > 0$, or $\theta_H(a) \to 0$ and $\delta_a > -\infty$. Thus, if δ_a is finite, then $d \log W_j(L, a)$ can be zero as long as $\beta_L \to \infty$. Moreover, if $\beta_L \to \infty$ and $\delta_a > 0$, then $d \log W_j(L, a) = 0$.

According to (A16), if $\delta_a \to -\infty$, then $d \log W_j(L, a) = -d \log G_j \neq 0$. Therefore, $d \log E_j(L, a) = 0$ and $d \log W_j(L, a) = 0$ only if $\beta_L \to \infty$. □

Proof of Lemma A5.

From (A15), if $\beta_x \to \infty$, then $d \log E_j(x, a) = 0$ for any $x \in \{H, L\}$. Hence, $\beta_x < \infty$ is a necessary condition for $d \log E_j(x, a) < 0$ when $d \log G_j < 0$.

Suppose that $\beta_x < \infty$. From (A16), $d \log W_j(x, a) = 0$ if and only if $\delta_a > -\infty$ and

$$(1 - \delta_a)\, s_{x'}(a)\, (\beta_{x'} - \beta_x) = 0.$$

Since $\beta_{x'} \neq \beta_x$, the latter will hold if and only if

1. $\delta_a = 1$, or

2. $s_{x'}(a) \to 0$.

From Lemmas A1 and A2, $s_{x'}(a) \to 0$ if and only if $\theta_{x'}(a) \to 0$, given that $\beta_x < \infty$ and $\delta_a > -\infty$. Since $\theta_{x'}(a) = 1 - \theta_x(a)$, then $\theta_{x'}(a) \to 0$ implies that $\theta_x(a) \to 1$.

Finally, from Lemma A4, if skill group x is observed in scenario a., then $\beta_x \to \infty$. □

Proof of Lemma A6.

From (A15), $d \log E_j(x, a) = 0$ if and only if one of the following conditions hold:

1. $\beta_x + s_{x'}(a) \frac{(1-\delta_a)\left(\beta_{x'} - \beta_x\right)}{1 - \delta_a + \beta_{x'}} \to \infty$ and $\delta_a > -\infty$.

2. $\delta_a \to -\infty$.

Condition 1. holds if and only if $\beta_x \to \infty$. Thus, $d \log E_j(x, a) = 0$ if and only if

1. $\beta_x \to \infty$, or

2. $\delta_a \to -\infty$,

or both.

Suppose that δ_a is finite. From (A16), we have that

$$\begin{aligned}\lim_{\beta_x\to\infty}\frac{d\log W_j(x,a)}{d\log G_j} &= -\lim_{\beta_x\to\infty}\frac{s_{x'}(a)\,(1-\delta_a)\,(\beta_{x'}-\beta_x)}{\beta_x\,(1-\delta_a+\beta_{x'})+s_{x'}(a)\,(1-\delta_a)\,(\beta_{x'}-\beta_x)}\\ &= \frac{s_{x'}(a)\,(1-\delta_a)}{\beta_{x'}+s_x(a)\,(1-\delta_a)},\end{aligned}$$

for $x\in\{H,L\}$ and $x'\neq x$. Thus, $d\log W_j(x,a)$ can be different from zero if $s_{x'}(a)\neq 0$ — i.e., $\delta_a<0$ according to Lemma A1 — and $\delta_a<1$. However, in this case, the elasticity of wages to amenities is positive.

Suppose that $\delta_a\to-\infty$. From (A16), we have that $d\log W_j(x,a)=-d\log G_j>0$ if $d\log G_j<0$. □

Proof of Lemma A7.

From (A17), $d\log E_j(L,a)=0$ if and only if one of the following conditions hold:

1. $\beta_L+\alpha+s_H\frac{(1-\delta_a-\alpha)(\beta_H-\beta_L)}{1-\delta_a+\beta_H}\to\infty$ and $\delta_a>-\infty$.

2. $\beta_L+\alpha\to\infty$ and $\delta_a\to-\infty$.

Both conditions hold if and only if $\beta_L\to\infty$.

Suppose δ_a is finite. From (A18), we have that

$$\begin{aligned}\lim_{\beta_L\to\infty}\frac{d\log W_j(L,a)}{d\log G_j} &= -\lim_{\beta_L\to\infty}\frac{\alpha+s_H(a)\frac{(1-\delta_a-\alpha)(\beta_H-\beta_L)}{1-\delta_a+\beta_H}}{\beta_L+\alpha+s_H(a)\frac{(1-\delta_a-\alpha)(\beta_H-\beta_L)}{1-\delta_a+\beta_H}}\\ &= \frac{s_H(a)\,(1-\delta_a-\alpha)}{1-\delta_a+\beta_H-s_H(a)\,(1-\delta_a-\alpha)},\end{aligned}$$

which equals zero if $s_H(a)=0$ or $\alpha=1-\delta_a$. Since $\alpha<1$, then $\alpha=1-\delta_a$ only if $\delta_a>0$. From Lemma A1, $s_H(a)\to 0$ if $\beta_L\to\infty$ and $\delta_a>0$ (or $\theta_H(a)\to 0$ and $\delta_a>-\infty$). Thus, if δ_a is finite, then $d\log W_j(L,a)$ can converge to zero as long as $\beta_L\to\infty$. In addition, a sufficient condition for $d\log W_j(L,a)\to 0$ is $\delta_a>0$.

Suppose that $\delta_a\to-\infty$ and $\beta_L\to\infty$. From (A18), we have that

$$\lim_{\beta_L\to\infty}\left[\lim_{\delta_a\to-\infty}\frac{d\log W_j(L,a)}{d\log G_j}\right]=-\lim_{\beta_L\to\infty}\left(\frac{\alpha}{\beta_L+\alpha}\right)=0.$$

Therefore, $d \log E_j(L,a) = 0$ and $d \log W_j(L,a) = 0$ only if $\beta_L \to \infty$. In addition to this necessary condition, a sufficient condition is that either $\delta_a \to -\infty$ or $\delta_a > 0$. $\square$

Proof of Lemma A8.

From (A17), if $\beta_x \to \infty$, then $d \log E_j(x,a) = 0$ for any $x \in \{H, L\}$. Hence, $\beta_x < \infty$ is a necessary condition for $d \log E_j(x,a) < 0$ when $d \log G_j < 0$.

Suppose that $\beta_x < \infty$. From (A18), $d \log W_j(x,a) = 0$ if and only if $\delta_a > -\infty$ and

$$(1-\delta_a)\, s_{x'}(a)\, (\beta_{x'} - \beta_x) + \alpha \left[s_{x'}(a)\beta_x + s_x(a)\beta_{x'} + 1 - \delta_a \right] = 0.$$

Since $\alpha > 0$ and $\beta_L \neq \beta_H$, this condition holds only if $\delta_a = 1$. In addition, the condition holds at the limit if $\beta_{x'} \to 0$ and, according to Lemmas A1 and A2, $\theta_{x'}(a) \to 0$ for $x \in \{H, L\}$ and $x' \neq x$. Since $\theta_{x'}(a) = 1 - \theta_x(a)$, then $\theta_{x'}(a) \to 0$ implies that $\theta_x(a) \to 1$.

Finally, from Lemma A7, if skill group x is observed in scenario a., then $\beta_x \to \infty$. $\square$

Proof of Lemma A9.

From (A17), $d \log E_j(x,a) = 0$ if and only if one of the following conditions hold:

1. $\beta_x + \alpha + s_{x'} \frac{(1-\delta_a-\alpha)\left(\beta_{x'}-\beta_x\right)}{1-\delta_a+\beta_{x'}} \to \infty$ and $\delta_a > -\infty$.

2. $\beta_x + \alpha \to \infty$ and $\delta_a \to -\infty$.

Both conditions hold if and only if $\beta_x \to \infty$.

Suppose δ_a is finite. From (A18), we have that

$$\begin{aligned}
\lim_{\beta_x \to \infty} \frac{d \log W_j(x,a)}{d \log G_j} &= - \lim_{\beta_x \to \infty} \frac{\alpha + s_{x'}(a) \frac{(1-\delta_a-\alpha)\left(\beta_{x'}-\beta_x\right)}{1-\delta_a+\beta_{x'}}}{\beta_x + \alpha + s_{x'}(a) \frac{(1-\delta_a-\alpha)\left(\beta_{x'}-\beta_x\right)}{1-\delta_a+\beta_{x'}}} \\
&= \frac{s_{x'}(a)\,(1-\delta_a-\alpha)}{1-\delta_a+\beta_{x'} - s_{x'}(a)\,(1-\delta_a-\alpha)},
\end{aligned}$$

for $x \in \{H, L\}$ and $x' \neq x$. Thus, $d \log W_j(x,a)$ can be different from zero if and only if $s_{x'}(a) \neq 0$ — i.e., $\delta_a < 0$ according to Lemma A1 — and $\alpha \neq 1 - \delta_a$, which holds if $\delta_a < 0$. However, if $\delta_a < 0$ and $\beta_x \to \infty$, then

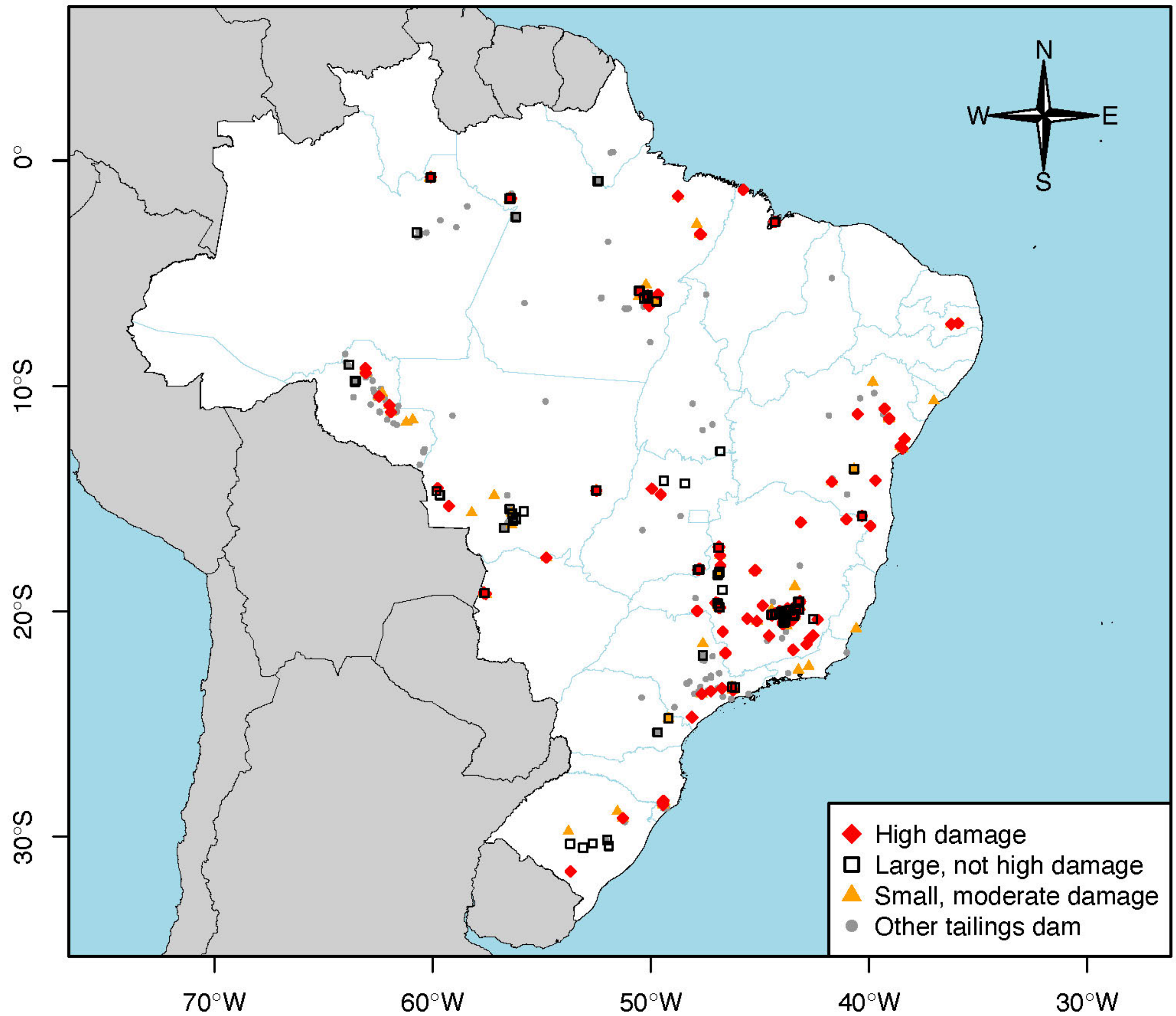
$$\frac{d \log W_j(x,a)}{d \log G_j} > 0.$$

Suppose that $\delta_a \to -\infty$. From (A18), we have that

$$\lim_{\beta_x \to \infty} \frac{d \log W_j(x,a)}{d \log G_j} = - \lim_{\beta_x \to \infty} \frac{\alpha}{\beta_x + \alpha} = 0$$

Therefore, $d \log E_j(x,a) = 0$ and $d \log W_j(x,a) \neq 0$ if and only if $\beta_x \to \infty$ and $\delta_a \in (-\infty, 0)$. Moreover, if $\beta_x \to \infty$ and $\delta_a \in (-\infty, 0)$, then the elasticity of wages to amenities is positive. $\square$

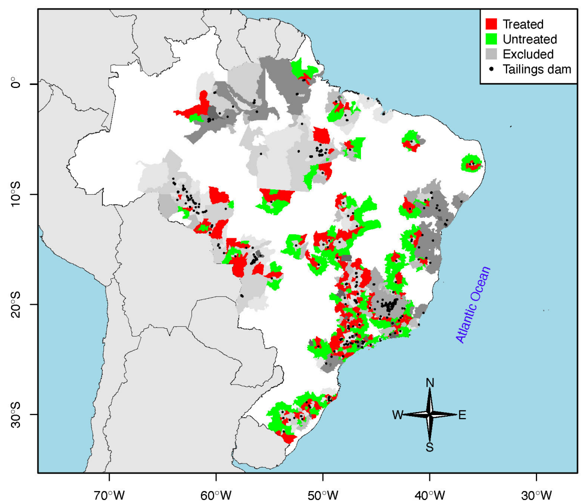
Figure S1: Location of Tailings Dams



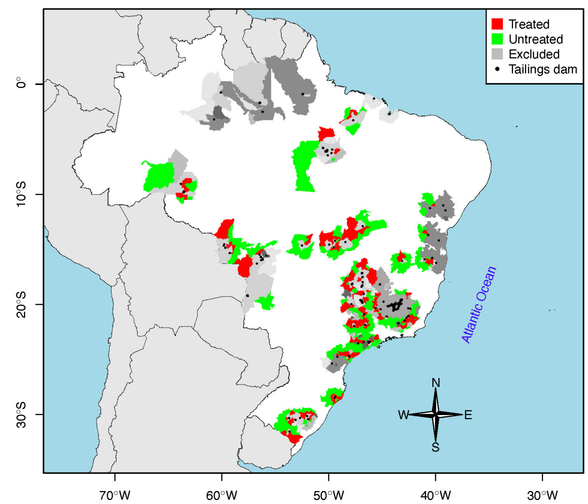
This figure presents a map of the 27 states in Brazil and the locations of tailings dams retaining hazardous waste from industrial and mining activities. The locations are based on the 2017 ANA safety dam report. 'High damage' dams are those where failure would cause a high level of damage, as defined in the report. 'Large, not high damage' dams are those with moderate or low potential damage but classified as large due to their size (i.e., structural height exceeding 15 meters or a capacity of more than three million cubic meters). 'Small, moderate damage' dams refer to those with moderate potential damage but small size. 'Other tailings dams' comprise all remaining small dams with a low level of potential damage.

Figure S2: Sample of Municipalities Depending on the Type of Tailings Dam Considered

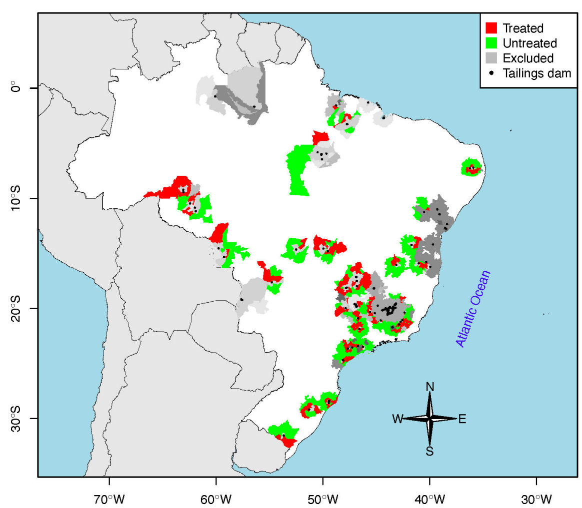
(a) All Dam Areas



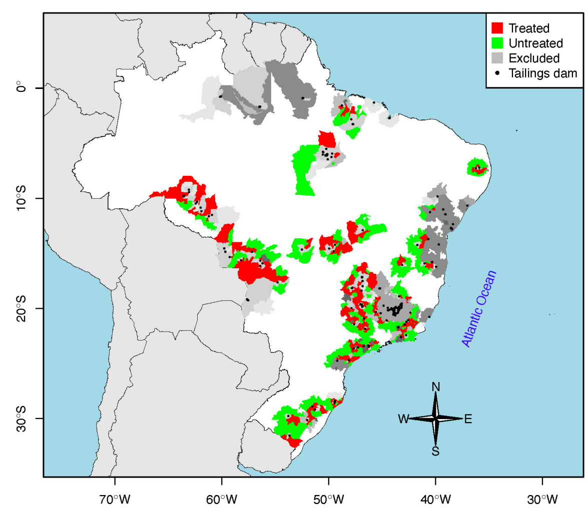
(b) Large Dam Areas



(c) High-Damage Dam Areas



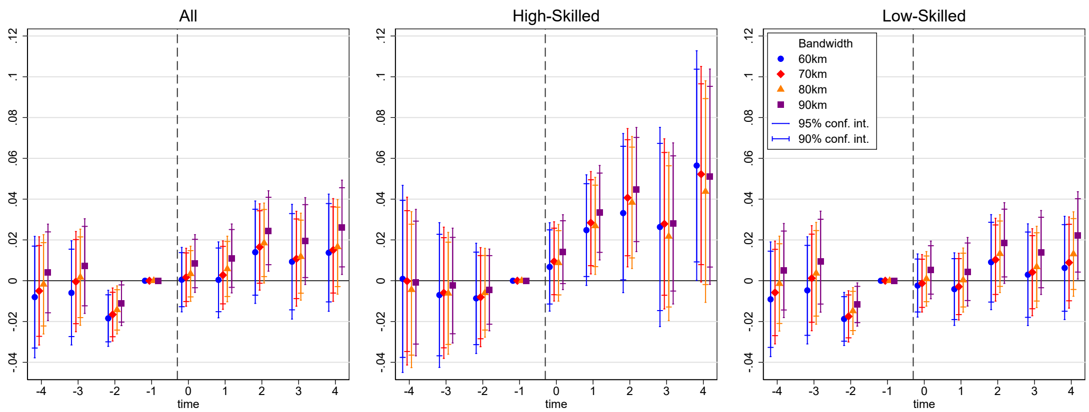
(d) Moderate-High Damage Dam Areas



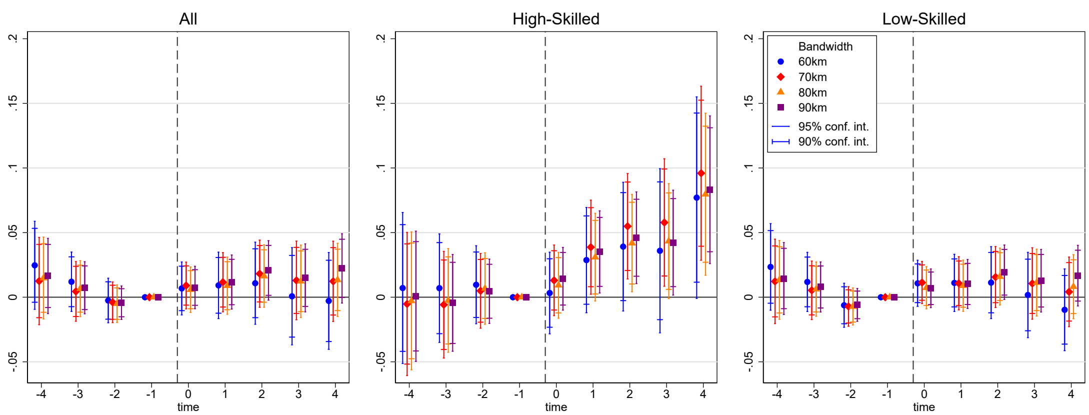
This figure shows the 'treated' municipalities, located downstream, and 'untreated' municipalities, located upstream, within 75 km of a large tailings dam. The maps present distinct samples based on the different types of tailings dams described in Section 3.1. 'Excluded' municipalities are those directly affected by dam failures, with a tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam.

Figure S3: Estimated Effects on Wages by Skill Level in Other Samples

(a) All Dam Areas



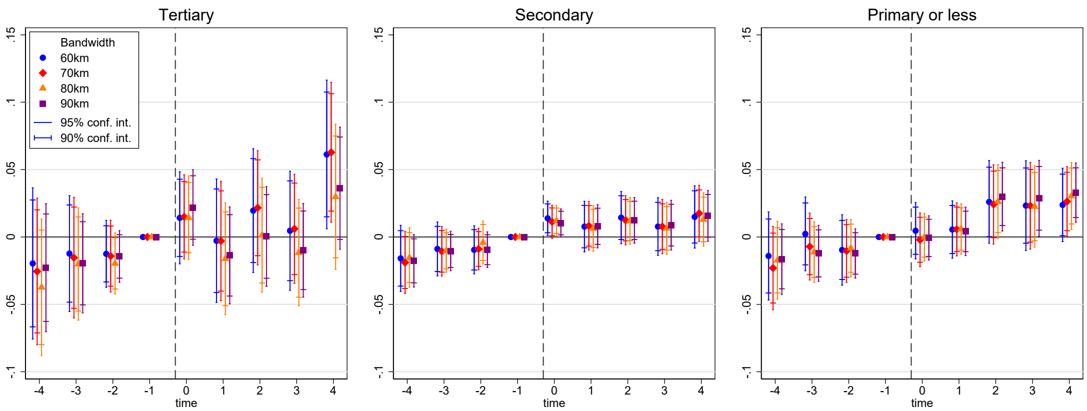
(b) Moderate-High Damage Dam Areas



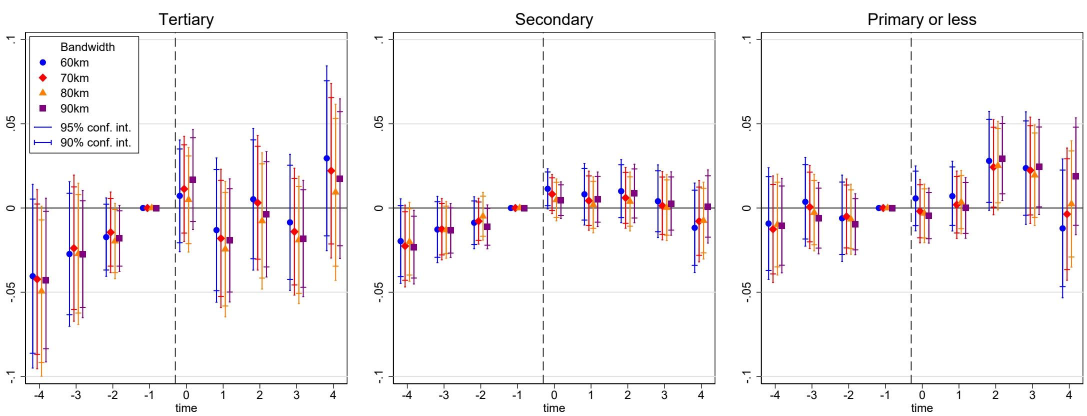
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the log of hourly wages on December 31 of each year. Based on the shortest distance to a dam, the diff-in-disc is estimated using four different bandwidths. The sample in panel (a) includes municipalities within the radius of any tailings dam. Panel (b) only considers municipalities close to a dam with moderate-high potential damage. In both panels, we exclude municipalities directly affected by dam failures, with a tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The left-hand graphs include all workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Among these workers, the middle and right-hand graphs consider only those in high- and low-skilled occupations, respectively. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S4: Estimated Effects on Wages by Education

(a) Large Dam Areas



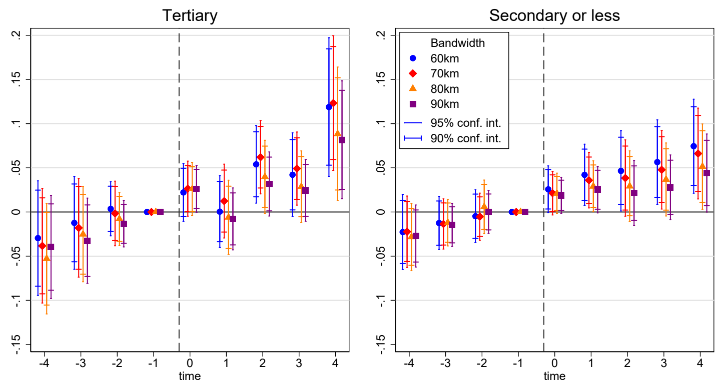
(b) High-Damage Dam Areas



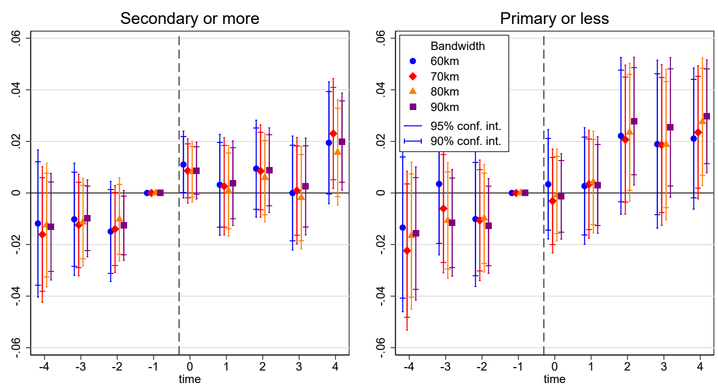
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the log of hourly wages on December 31 of each year. Based on the shortest distance to a dam, the diff-in-disc is estimated using four different bandwidths. The sample in panel (a) includes municipalities within the radius of a large tailings dam. Panel (b) only considers municipalities close to a high-damage dam. In both panels, we exclude municipalities directly affected by dam failures, with a large or high-damage tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. The left-hand graphs consider only workers with complete tertiary education. The middle graphs consider only those with complete secondary education but no tertiary degree. The right-hand graphs consider only those with incomplete secondary education or less. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S5: Estimated Effects on Wages by Skill Level and Education

(a) High-Skilled Workers



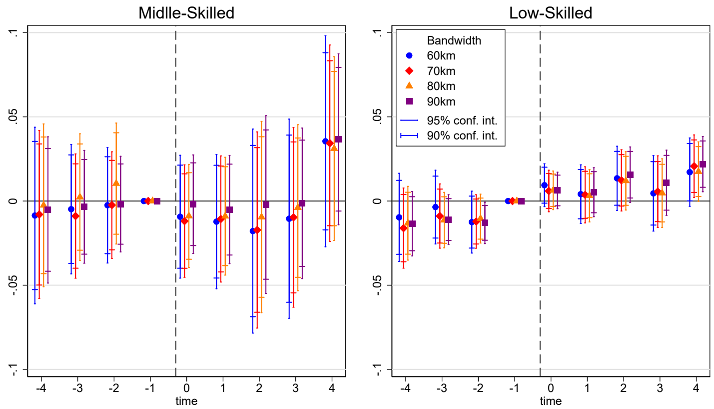
(b) Low-Skilled Workers



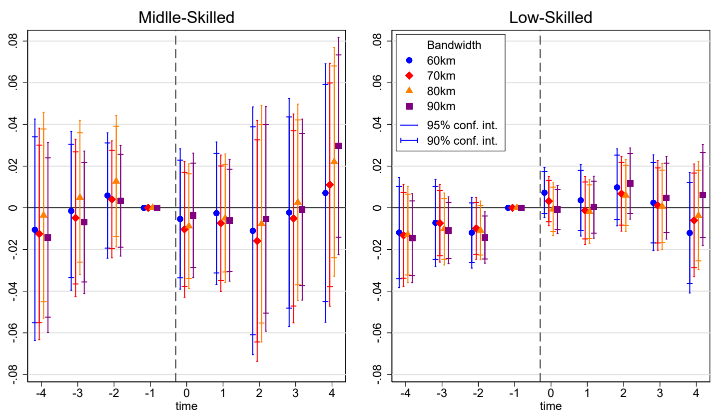
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a large tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the log of hourly wages on December 31 of each year. Based on the shortest distance to a large tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a large tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Panel (a) only considers those workers in high-skilled occupations, separating them into those with complete tertiary education on the left-hand side and incomplete tertiary education or less on the right-hand side. Panel (b) only considers those in low-skilled occupations, separating them into those with complete secondary education on the left-hand side and incomplete secondary education or less on the right-hand side. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S6: Estimated Effects on Wages by Subgroups of Low-Skilled Workers

(a) Large Dam Areas



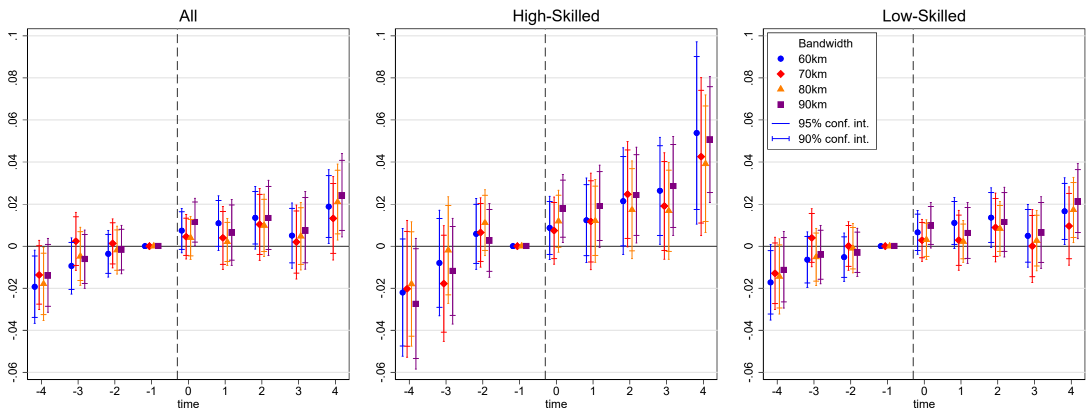
(b) High-Damage Dam Areas



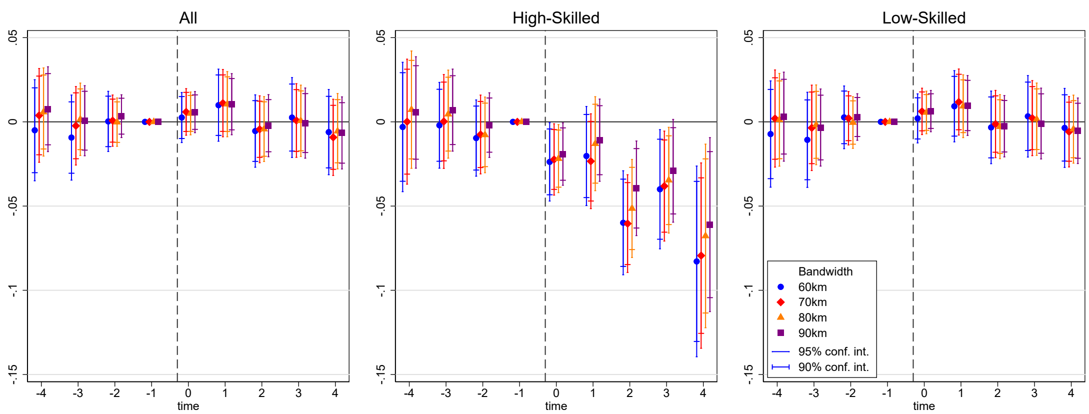
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the log of hourly wages on December 31 of each year. Based on the shortest distance to a dam, the diff-in-disc is estimated using four different bandwidths. The sample in panel (a) includes municipalities within the radius of a large tailings dam. Panel (b) only considers municipalities close to a high-damage dam. In both panels, we exclude municipalities directly affected by dam failures, with a large or high-damage tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all workers between 25 and 60 years old in the selected municipalities, excluding high-skilled workers, temporary workers, and those employed in mining, agriculture, and the public sector. The left-hand graphs consider only workers occupied as skilled technicians or low-level managers, referred to as 'middle-skilled' workers. The right-hand graphs consider the other low-skilled workers. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S7: Estimated Effects on Wages by Skill Level with Random Control Group

(a) Downstream Municipalities Compared to Random Control Group



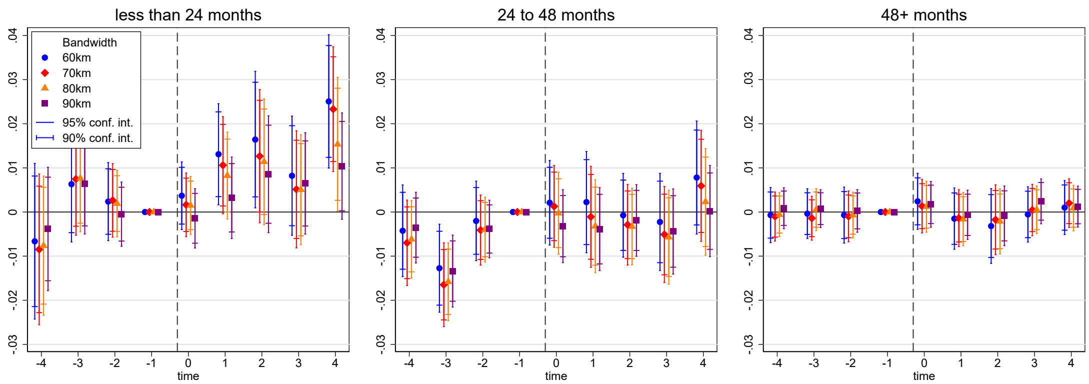
(b) Upstream Municipalities Compared to Random Control Group



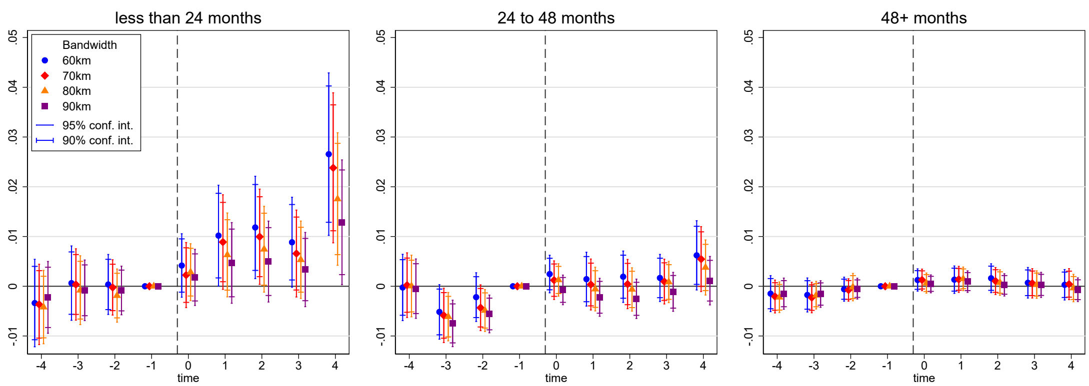
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the log of hourly wages on December 31 of each year. In panel (a), we compare workers in treated municipalities, located downstream of a large tailings dam, with workers in a random group of municipalities. In panel (b), we compare workers in upstream municipalities, located close to a large tailings dam, with workers in a random group of municipalities. In both panels, the number of control municipalities is the same as in our baseline estimations. Based on the shortest distance to a large tailings dam, the diff-in-disc is estimated using four different bandwidths, but only upstream and downstream municipalities are subject to them. The sample excludes municipalities directly affected by dam failures, with a large or high-damage tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all high-skilled workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S8: Estimated Effects on the Probability of Resignation by Job Tenure

(a) High-Skilled Workers



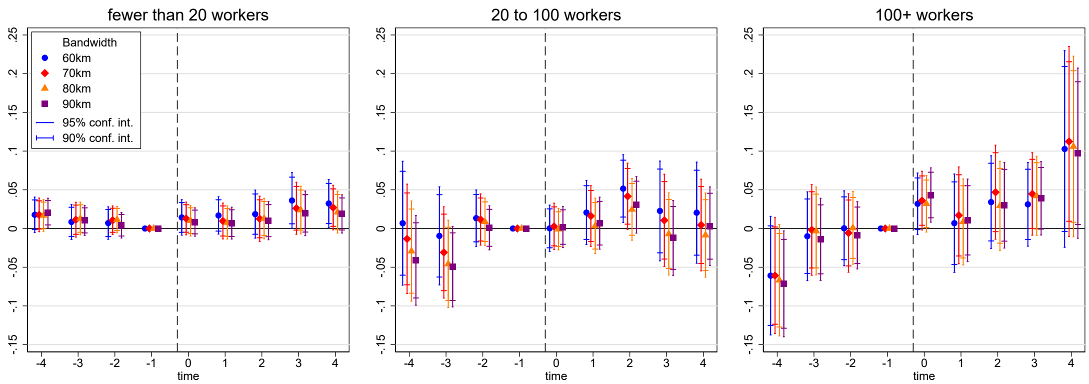
(b) Low-Skilled Workers



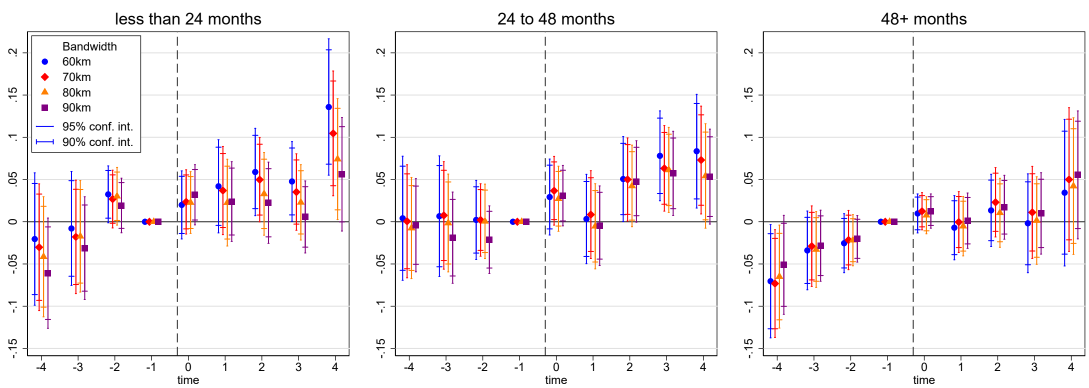
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing treated municipalities, located downstream of a large tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is equal to one if the worker resigns or retires from their job in which they have been regularly employed since December 31 of the previous year and zero otherwise. Based on the shortest distance to a large tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a large tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Panel (a) only considers those workers in high-skilled occupations. Panel (b) only considers those in low-skilled occupations. In both panels, workers are separated based on their current job tenure. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S9: Estimated Effects on the Wages of High-Skilled Workers by Firm Size and Job Tenure in Areas Closed to High-Damage Dams

(a) By Firm Size



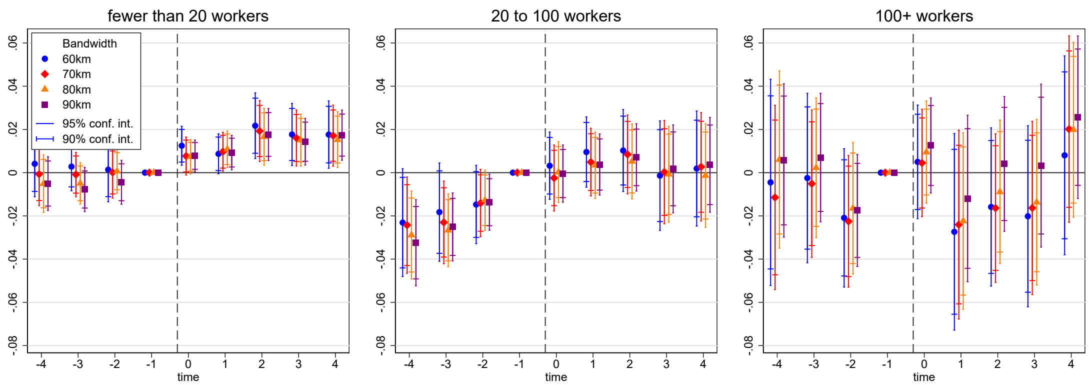
(b) By Job Tenure



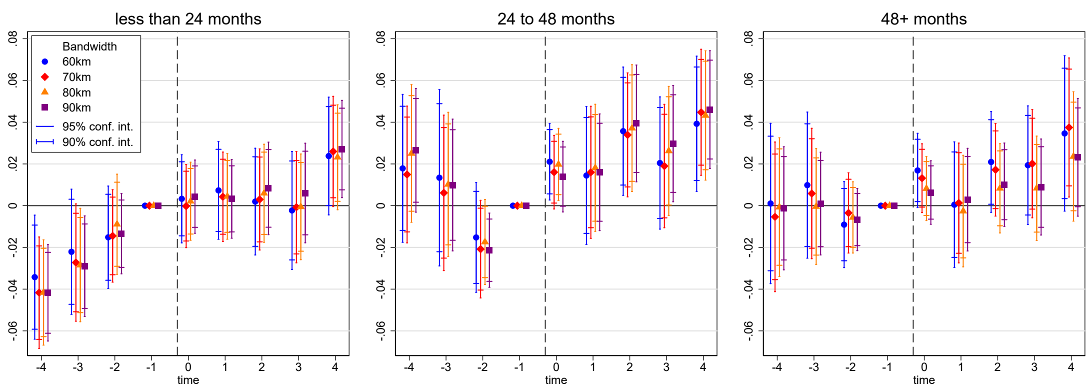
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a high-damage tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the log of hourly wages on December 31 of each year. Based on the shortest distance to a high-damage tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a high-damage tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all high-skilled workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Panel (a) separates high-skilled workers based on the number of regular, full-time equivalent employees in their current business establishment. Panel (b) separates high-skilled workers based on their current job tenure. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S10: Estimated Effects on the Wages of Low-Skilled Workers by Firm Size and Job Tenure

(a) By Firm Size



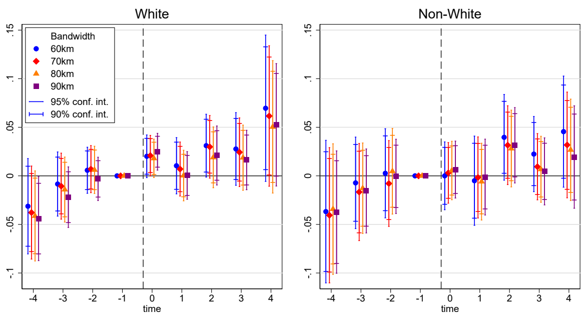
(b) By Job Tenure



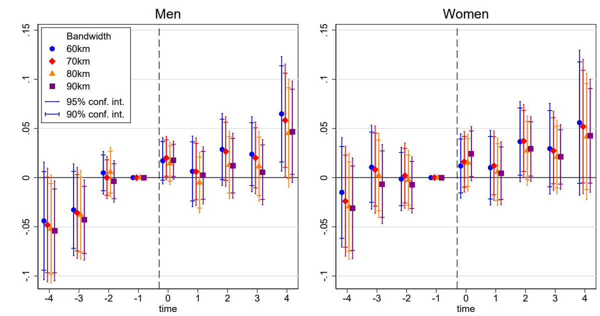
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a large tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the log of hourly wages on December 31 of each year. Based on the shortest distance to a large tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a large tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all low-skilled workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Panel (a) separates low-skilled workers based on the number of regular, full-time equivalent employees in their current business establishment. Panel (b) separates low-skilled workers based on their current job tenure. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S11: Estimated Effects on the Wages of High-Skilled Workers by Race, Gender, and Sub-Occupation in Areas Closed to High-Damage Dams

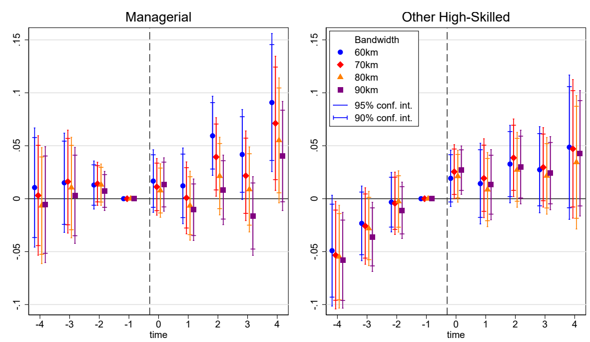
(a) By Race



(b) By Gender



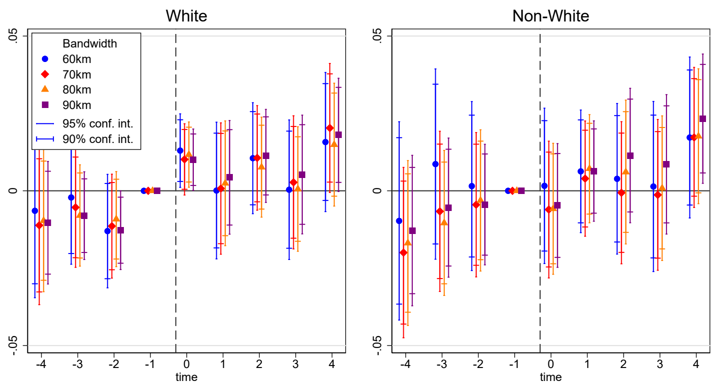
(c) By Sub-Occupation



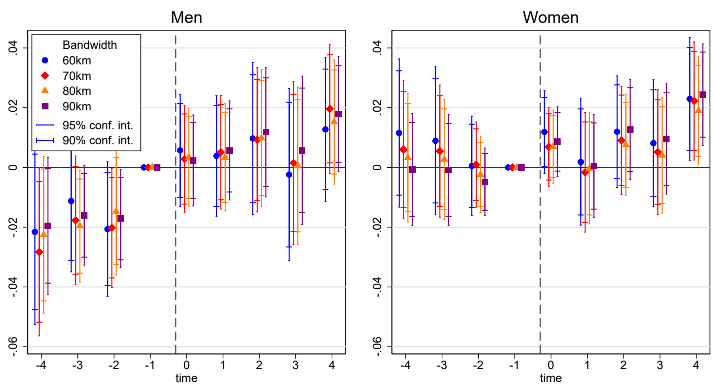
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a high-damage tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the log of hourly wages on December 31 of each year. Based on the shortest distance to a high-damage tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a high-damage tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all high-skilled workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Panel (a) separates high-skilled workers based on race. Dark-skinned and indigenous workers are referred to as 'non-white,' and the other workers, including Asians, are referred to as 'white.' Panel (b) separates high-skilled workers based on gender at birth. Panel (c) separates high-skilled workers based on whether they occupy a managerial position or not. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S12: Estimated Effects on the Wages of Low-Skilled Workers by Race and Gender

(a) By Race

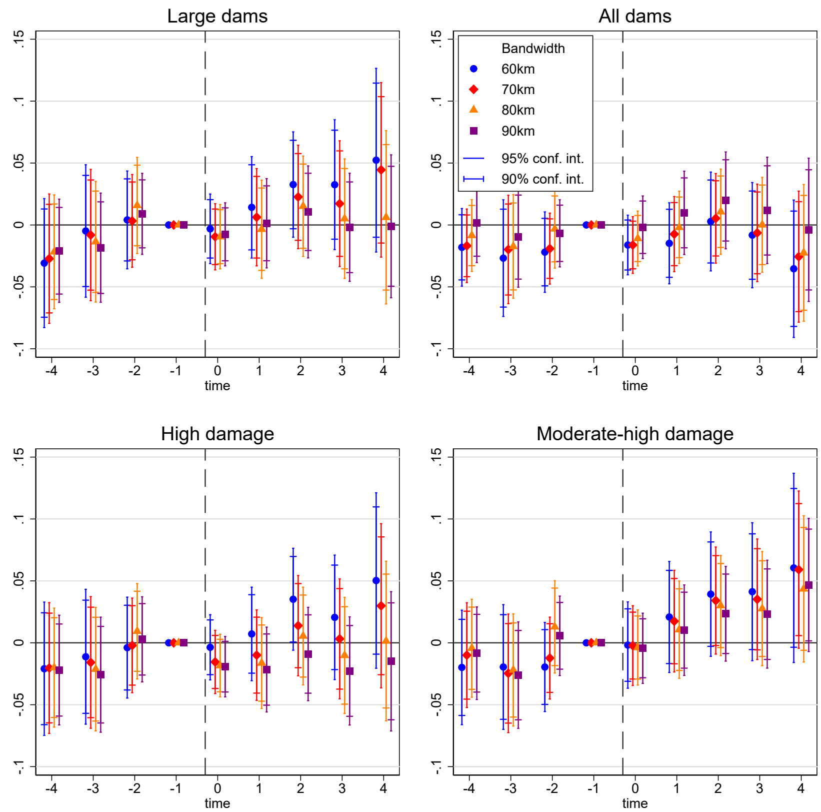


(b) By Gender



This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a large tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the log of hourly wages on December 31 of each year. Based on the shortest distance to a large tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a large tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all low-skilled workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Panel (a) separates low-skilled workers based on race. Dark-skinned and indigenous workers are referred to as 'non-white,' and the other workers, including Asians, are referred to as 'white.' Panel (b) separates low-skilled workers based on gender at birth. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

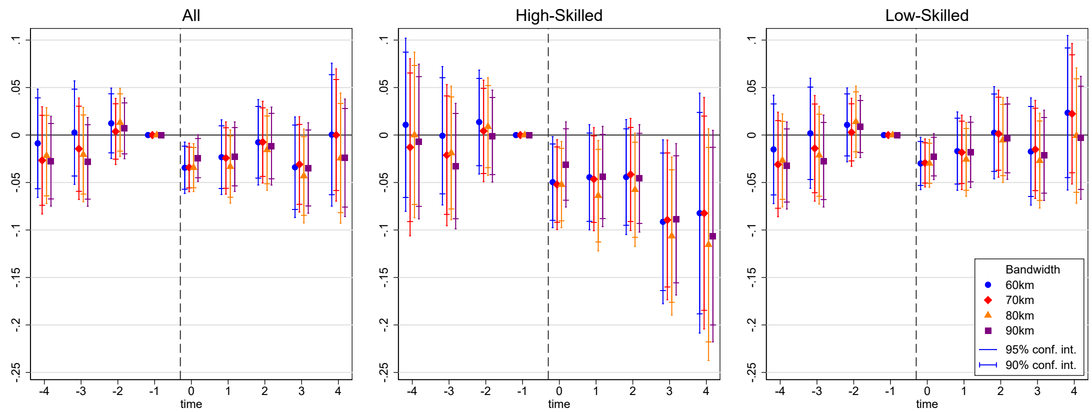
Figure S13: Estimated Effects on Establishment Size by Type of Area



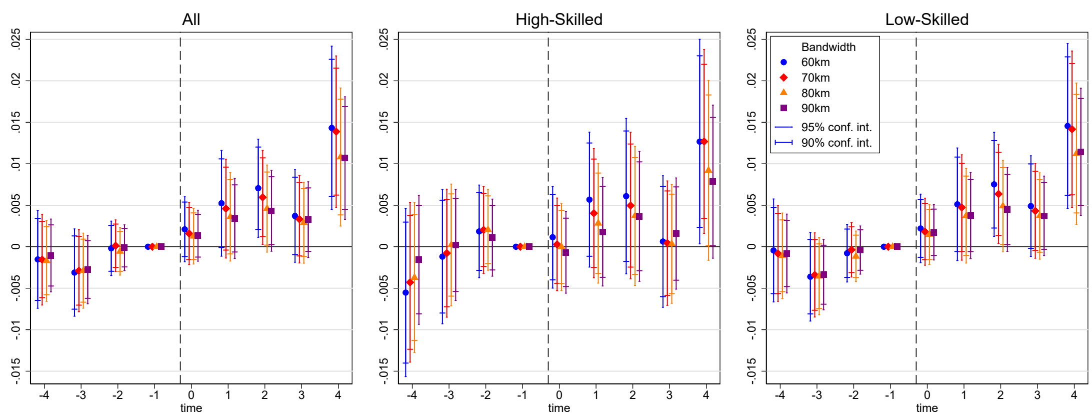
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing business establishments in treated municipalities, located downstream of a tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the number of full-time equivalent workers regularly employed by the establishment on December 31 of each year. Based on the shortest distance to a tailings dam, the diff-in-disc is estimated using four different bandwidths. The four graphs use different samples of municipalities. The top-left graph ('large dams') only includes municipalities within the radius of a large tailings dam. The top-right graph ('all dams') considers all municipalities within the radius of any tailings dam. The bottom-left graph ('high-damage') only includes municipalities within the radius of a tailings dam officially rated as highly damaging in case of failure. The bottom-right graph ('moderate-high damage') only includes municipalities within the radius of a tailings dam with potential damage officially rated as moderate or high. For all graphs, we exclude municipalities directly affected by dam failures, with a tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample of firms excludes those in mining, agriculture, and public services. The diff-in-disc is estimated using log-linear Poisson regressions with municipality fixed-effects and a dummy for each year.

Figure S14: Estimated Effects on Employment and Resignations by Skill Level in Areas Closed to High-Damage Dams

(a) Number of Employed Workers (in log)



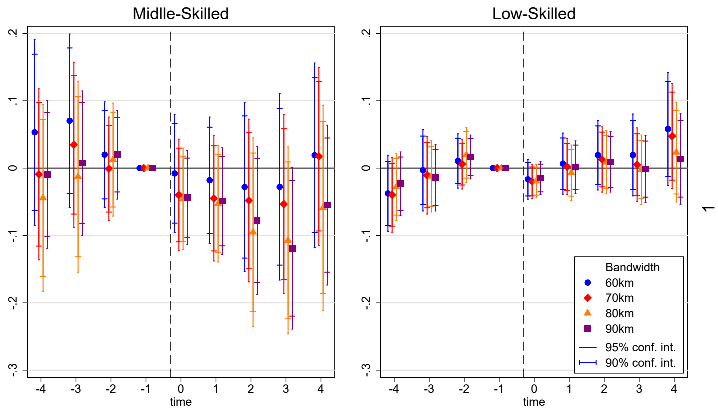
(b) Probability of Resignation



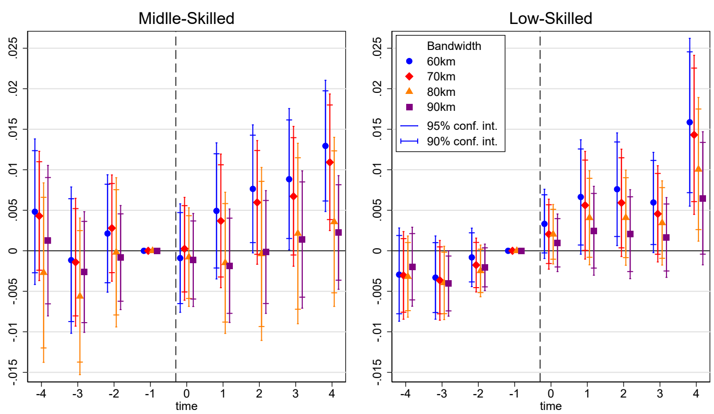
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing treated municipalities, located downstream of a high-damage tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. Based on the shortest distance to a high-damage tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a high-damage tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The left-hand graphs consider all workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Among these workers, the middle and right-hand graphs consider only those in high- and low-skilled occupations, respectively. In panel (a), the dependent variable is the number of full-time equivalent workers regularly employed in the municipality on December 31 of each year. For this variable, the diff-in-disc is estimated using log-linear Poisson regressions with municipality fixed-effects and a dummy for each year. In panel (b), the dependent variable is equal to one if the worker resigns or retires from their job in which they have been regularly employed since December 31 of the previous year and zero otherwise. For this variable, the diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S15: Estimated Effects on Employment and Resignations by Subgroups of Low-Skilled Workers

(a) Number of Employed Workers (in log)



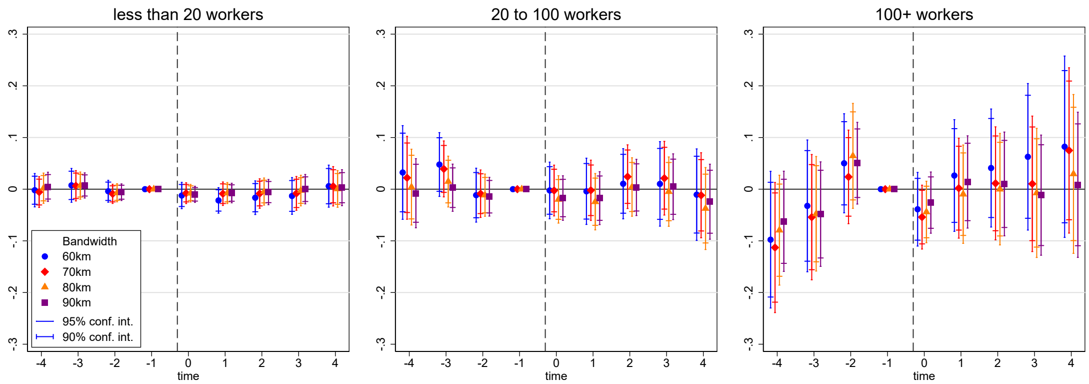
(b) Probability of Resignation



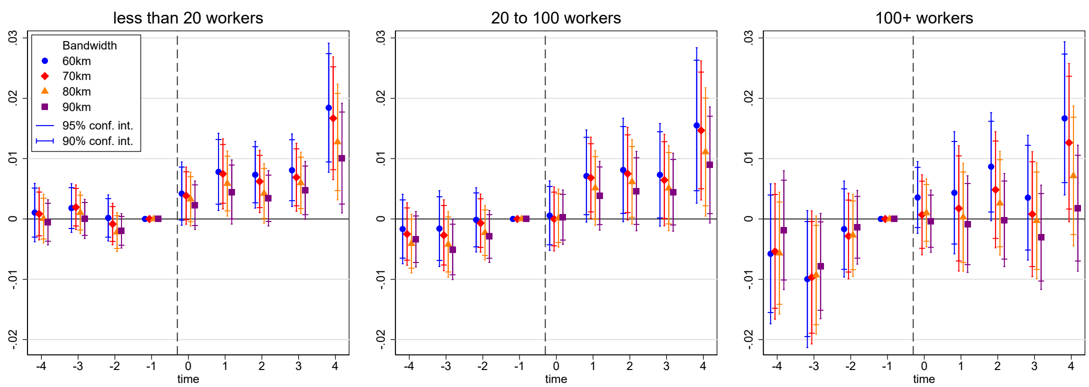
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing treated municipalities, located downstream of a large tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. Based on the shortest distance to a large tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a large tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The left-hand graphs consider only workers occupied as skilled technicians or low-level managers, referred to as 'middle-skilled' workers. The right-hand graphs consider the other low-skilled workers. In panel (a), the dependent variable is the number of full-time equivalent workers regularly employed in the municipality on December 31 of each year. For this variable, the diff-in-disc is estimated using log-linear Poisson regressions with municipality fixed-effects and a dummy for each year. In panel (b), the dependent variable is equal to one if the worker resigns or retires from their job in which they have been regularly employed since December 31 of the previous year and zero otherwise. For this variable, the diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S16: Estimated Effects on Low-Skilled Employment and Resignations by Firm Size

(a) Number of Employed Workers (in log)



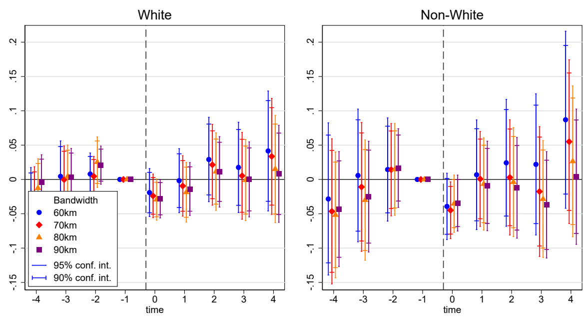
(b) Probability of Resignation



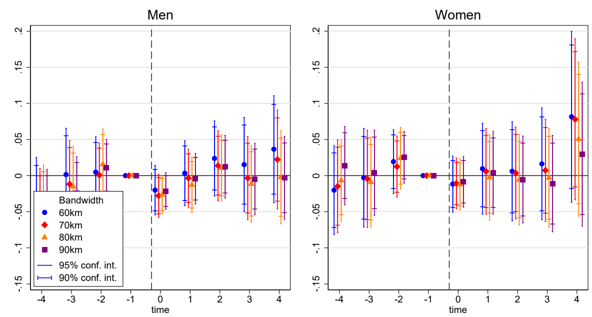
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a large tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. Based on the shortest distance to a large tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a large tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all low-skilled workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. The left-hand graphs consider only workers in micro establishments, with fewer than 20 regular, full-time equivalent employees. The middle graphs consider only workers in small establishments, with 20 to 100 regular, full-time equivalent employees. The right-hand graphs consider only workers in large establishments, with more than 100 regular, full-time equivalent employees. In panel (a), the dependent variable is the number of full-time equivalent workers regularly employed in the municipality on December 31 of each year. For this variable, the diff-in-disc is estimated using log-linear Poisson regressions with municipality fixed-effects and a dummy for each year. In panel (b), the dependent variable is equal to one if the worker resigns or retires from their job in which they have been regularly employed since December 31 of the previous year and zero otherwise. For this variable, the diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S17: Estimated Effects on Low-Skilled Employment by Race, Gender, and Education

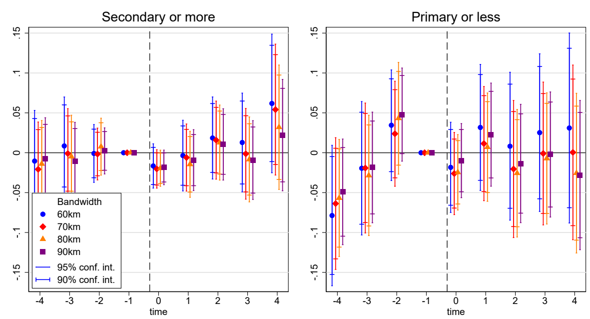
(a) By Race



(b) By Gender



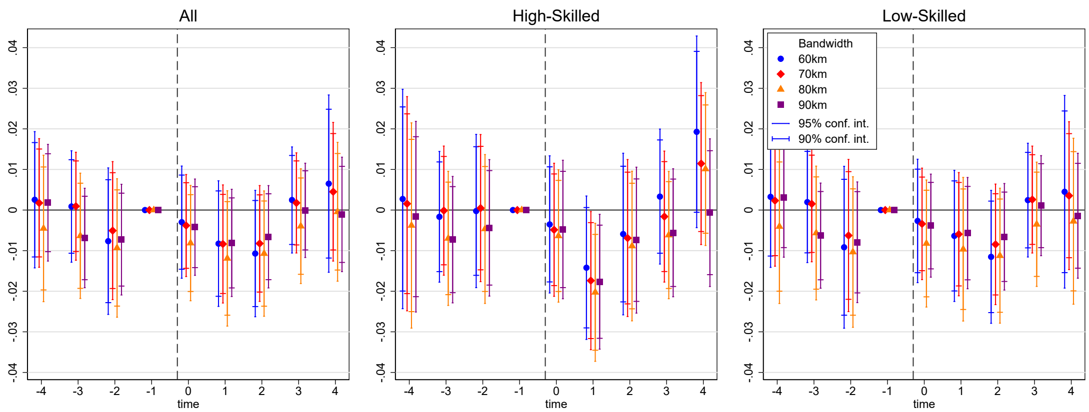
(c) By Education



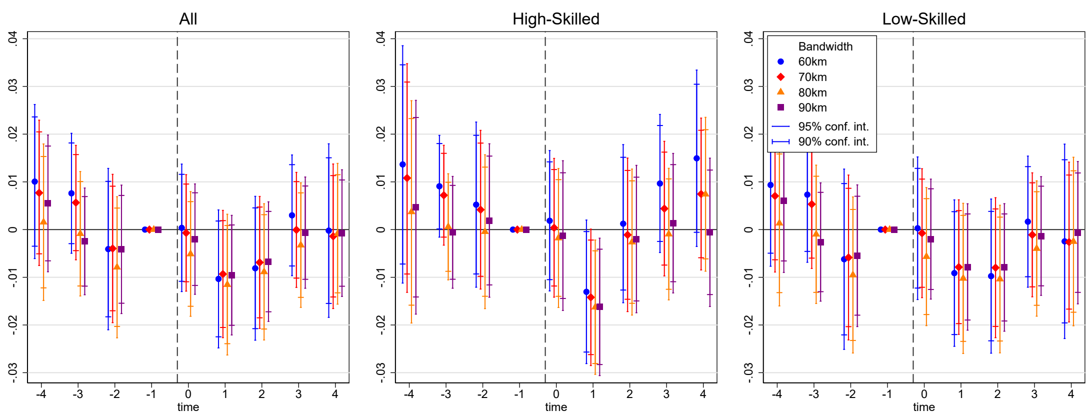
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a large tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the number of full-time equivalent workers regularly employed in the municipality on December 31 of each year. Based on the shortest distance to a large tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a large tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all low-skilled workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Panel (a) separates low-skilled workers based on race. Dark-skinned and indigenous workers are referred to as 'non-white,' and the other workers, including Asians, are referred to as 'white.' Panel (b) separates low-skilled workers based on gender at birth. Panel (c) separates low-skilled workers based on their highest level of education. The diff-in-disc is estimated using log-linear Poisson regressions with municipality fixed-effects and a dummy for each year.

Figure S18: Estimated Effects on the Probability of Layoff by Skill Level

(a) Large Dam Areas



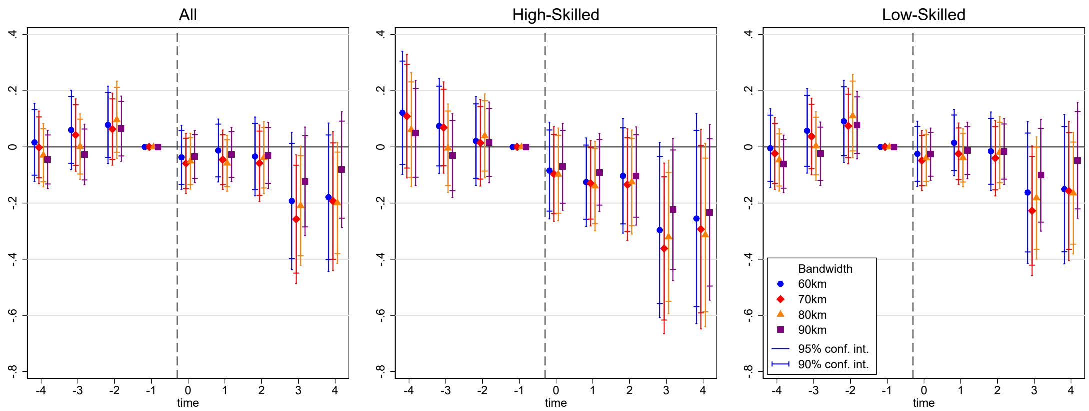
(b) High-Damage Dam Areas



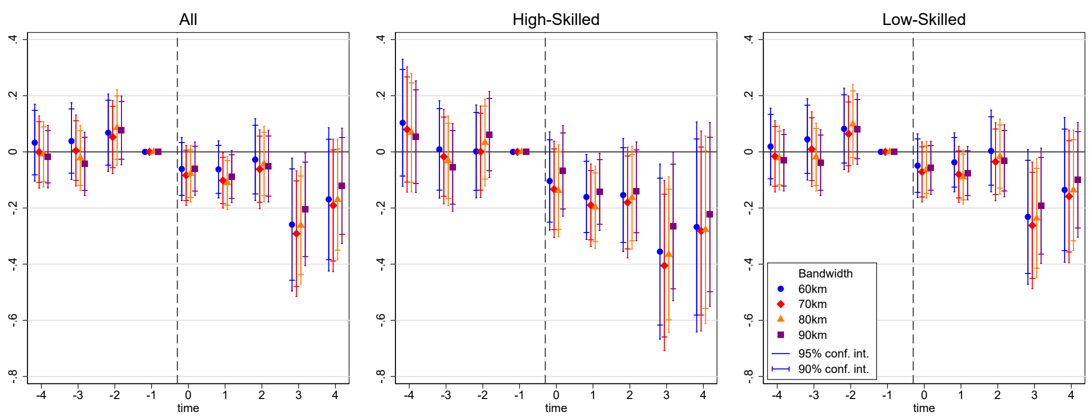
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is equal to one if the worker's contract was terminated by the employer for which they have worked since December 31 of the previous year and zero otherwise. Based on the shortest distance to a dam, the diff-in-disc is estimated using four different bandwidths. The sample in panel (a) only includes municipalities within the radius of a large tailings dam. Panel (b) only considers municipalities close to a high-damage dam. In both panels, we exclude municipalities directly affected by dam failures, with a large or high-damage tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The left-hand graphs consider all workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Among these workers, the middle and right-hand graphs consider only those in high- and low-skilled occupations, respectively. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S19: Estimated Effects on the Arrival of New Workers by Skill Level

(a) Large Dam Areas



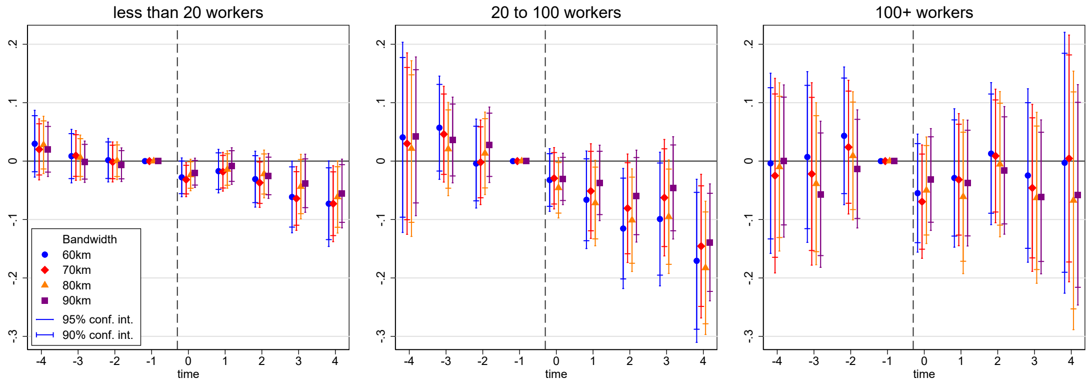
(b) High-Damage Dam Areas



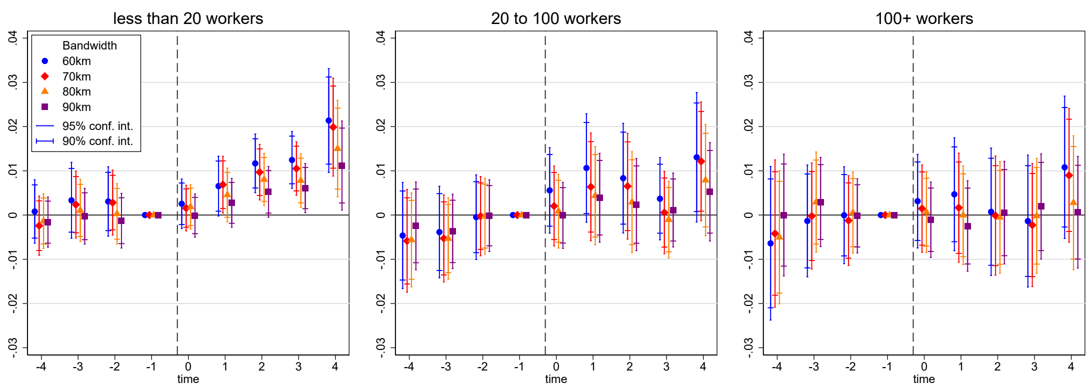
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing treated municipalities, located downstream of a tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the number of full-time equivalent workers who appeared regularly employed for the first time in the municipality on December 31 of each year. Workers who had already appeared in any sector or occupations or with a temporary contract within the municipality are not counted. Based on the shortest distance to a dam, the diff-in-disc is estimated using four different bandwidths. The sample in panel (a) only includes municipalities within the radius of a large tailings dam. Panel (b) only considers municipalities close to a high-damage dam. In both panels, we exclude municipalities directly affected by dam failures, with a large or high-damage tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The left-hand graphs consider all new workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Among these workers, the middle and right-hand graphs consider only those in high- and low-skilled occupations, respectively. The diff-in-disc is estimated using log-linear Poisson regressions with municipality fixed-effects and a dummy for each year.

Figure S20: Estimated Effects on High-Skilled Employment and Resignations by Firm Size

(a) Number of Employed Workers (in log)



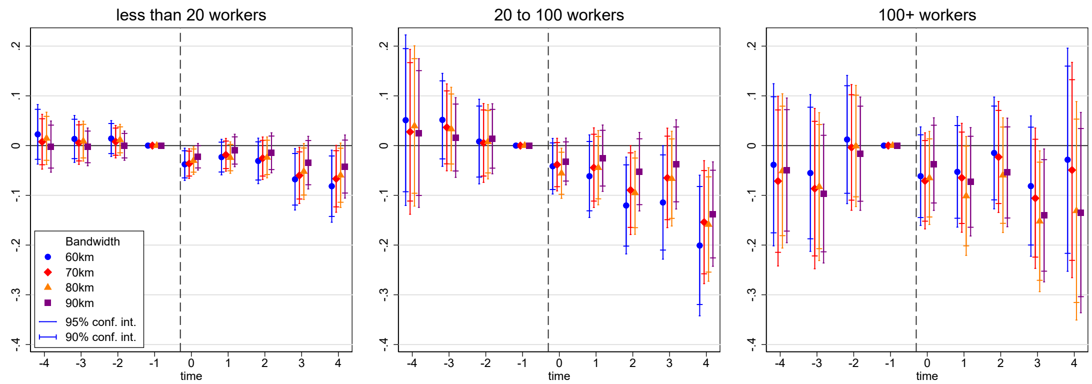
(b) Probability of Resignation



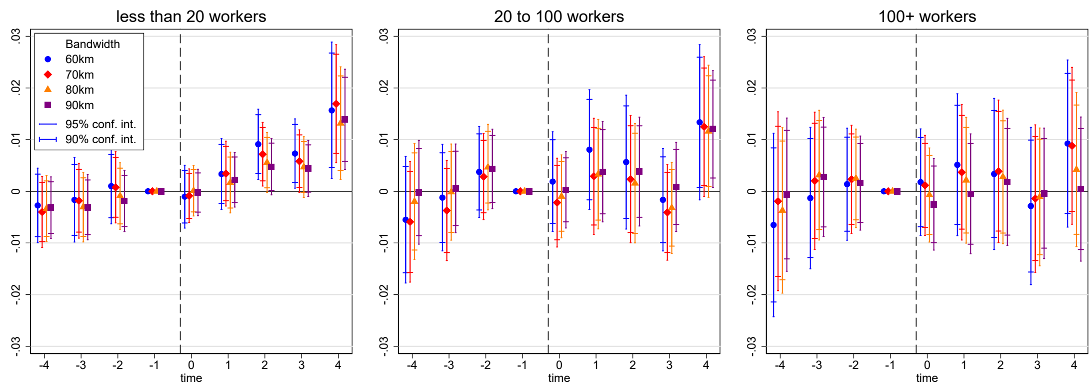
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a large tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. Based on the shortest distance to a large tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a large tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all high-skilled workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. The left-hand graphs consider only workers in micro establishments, with fewer than 20 regular, full-time equivalent employees. The middle graphs consider only workers in small establishments, with 20 to 100 regular, full-time equivalent employees. The right-hand graphs consider only workers in large establishments, with more than 100 regular, full-time equivalent employees. In panel (a), the dependent variable is the number of full-time equivalent workers regularly employed in the municipality on December 31 of each year. For this variable, the diff-in-disc is estimated using log-linear Poisson regressions with municipality fixed-effects and a dummy for each year. In panel (b), the dependent variable is equal to one if the worker resigns or retires from their job in which they have been regularly employed since December 31 of the previous year and zero otherwise. For this variable, the diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S21: Estimated Effects on High-Skilled Employment and Resignations by Firm Size in Areas Closed to High-Damage Dams

(a) Number of Employed Workers (in log)



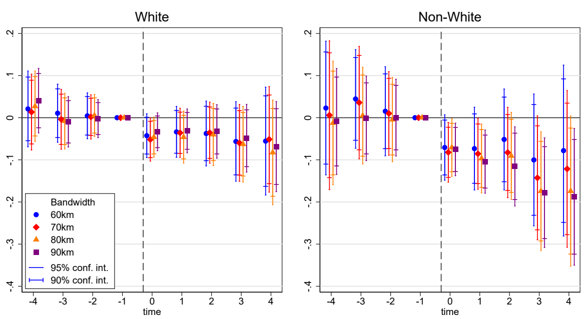
(b) Probability of Resignation



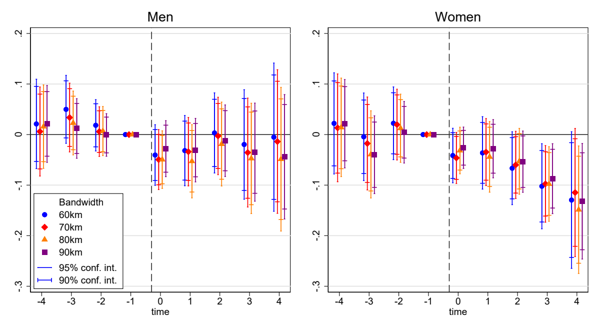
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a high-damage tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. Based on the shortest distance to a high-damage tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a high-damage tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all high-skilled workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. The left-hand graphs consider only workers in micro establishments, with fewer than 20 regular, full-time equivalent employees. The middle graphs consider only workers in small establishments, with 20 to 100 regular, full-time equivalent employees. The right-hand graphs consider only workers in large establishments, with more than 100 regular, full-time equivalent employees. In panel (a), the dependent variable is the number of full-time equivalent workers regularly employed in the municipality on December 31 of each year. For this variable, the diff-in-disc is estimated using log-linear Poisson regressions with municipality fixed-effects and a dummy for each year. In panel (b), the dependent variable is equal to one if the worker resigns or retires from their job in which they have been regularly employed since December 31 of the previous year and zero otherwise. For this variable, the diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S22: Estimated Effects on High-Skilled Employment by Race, Gender, Education, and Sub-Occupation

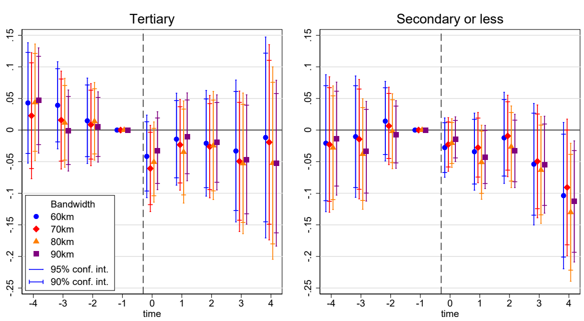
(a) By Race



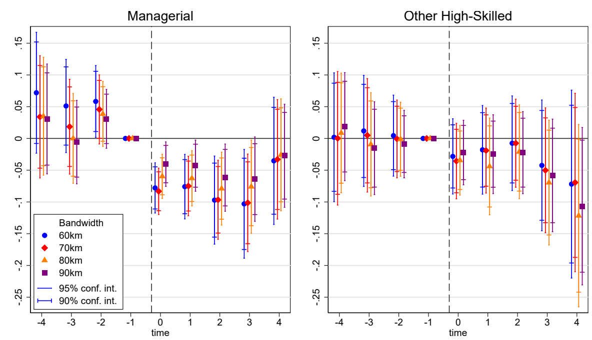
(b) By Gender



(c) By Education



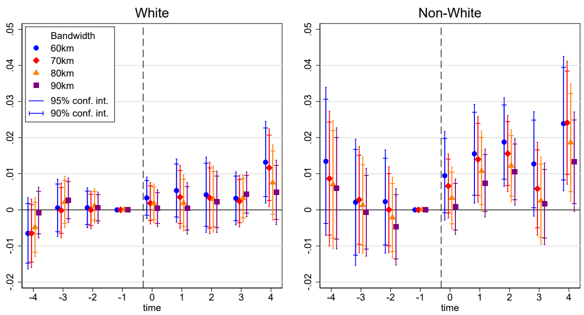
(d) By Sub-Occupation



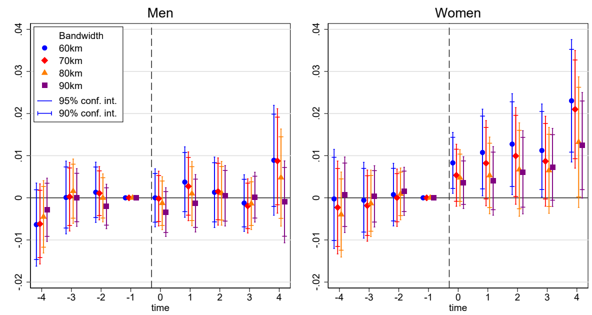
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a large tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the number of full-time equivalent workers regularly employed in the municipality on December 31 of each year. Based on the shortest distance to a large tailings dam, the diff-in-disc is estimated using four different bandwidths.The sample excludes municipalities directly affected by dam failures, with a large tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all high-skilled workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Panel (a) separates high-skilled workers based on race. Dark-skinned and indigenous workers are referred to as 'non-white,' and the other workers, including Asians, are referred to as 'white.' Panel (b) separates high-skilled workers based on gender at birth. Panel (c) separates high-skilled workers based on their highest level of education. Panel (d) separates high-skilled workers based on whether they occupy a managerial position or not. The diff-in-disc is estimated using log-linear Poisson regressions with municipality fixed-effects and a dummy for each year.

Figure S23: Estimated Effects on the Probability of Resignation of High-Skilled Workers by Race, Gender, Education, and Sub-Occupation

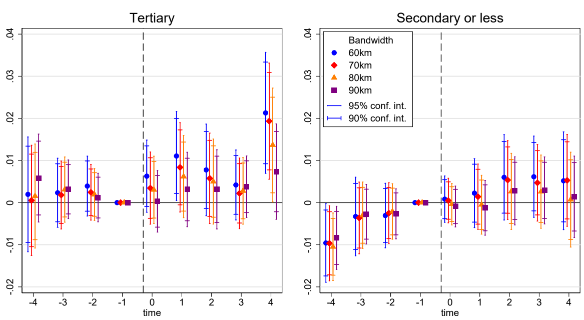
(a) By Race



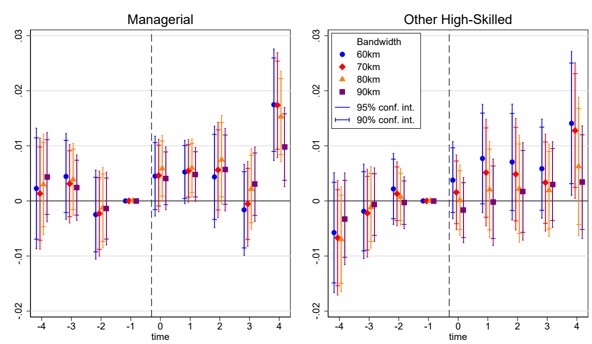
(b) By Gender



(c) By Education



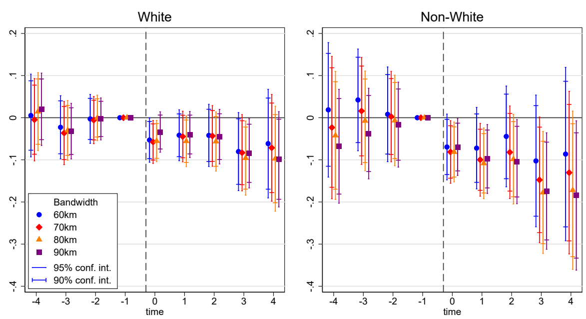
(d) By Sub-Occupation



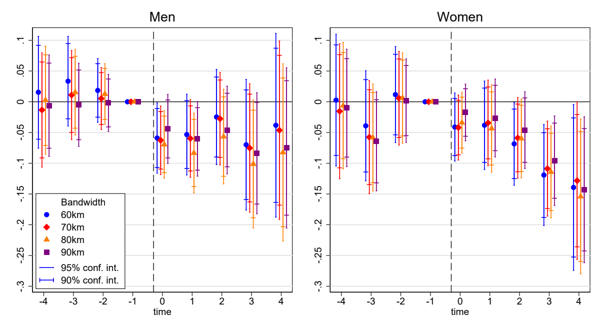
This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a large tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is equal to one if the worker resigns or retires from their job in which they have been regularly employed since December 31 of the previous year and zero otherwise. Based on the shortest distance to a large tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a large tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all high-skilled workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Panel (a) separates high-skilled workers based on race. Dark-skinned and indigenous workers are referred to as 'non-white,' and the other workers, including Asians, are referred to as 'white.' Panel (b) separates high-skilled workers based on gender at birth. Panel (c) separates high-skilled workers based on their highest level of education. Panel (d) separates high-skilled workers based on whether they occupy a managerial position or not. The diff-in-disc is estimated using local linear regressions with municipality fixed-effects and year-specific effects. Robust confidence intervals are calculated using standard errors clustered at the municipality level.

Figure S24: Estimated Effects on High-Skilled Employment by Race, Gender, Education, and Sub-Occupation in Areas Closed to High-Damage Dams

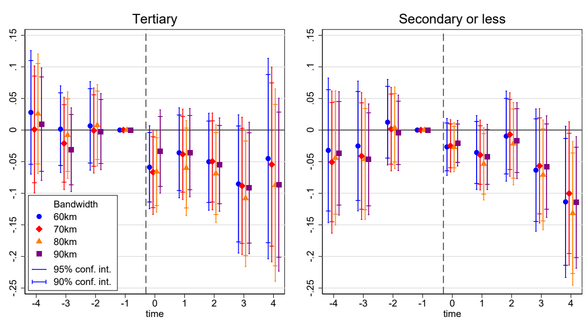
(a) By Race



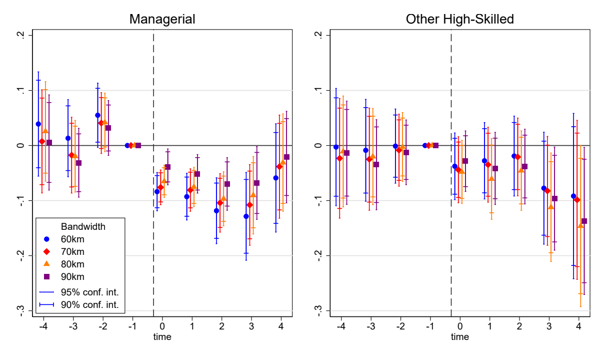
(b) By Gender



(c) By Education



(d) By Sub-Occupation



This figure exhibits the diff-in-disc estimates (in the vertical axis), along with robust confidence intervals, obtained by comparing workers in treated municipalities, located downstream of a high-damage tailings dam, and untreated municipalities, located upstream, over the years (in the horizontal axis). The dashed vertical line represents the moment of the dam collapse in Mariana in 2015. The dependent variable is the number of full-time equivalent workers regularly employed in the municipality on December 31 of each year. Based on the shortest distance to a high-damage tailings dam, the diff-in-disc is estimated using four different bandwidths. The sample excludes municipalities directly affected by dam failures, with a high-damage tailings dam within their jurisdiction, receiving oil royalties, or with a population over half million people. We also exclude untreated municipalities located downstream of any tailings dam within 200 km and treated municipalities without an untreated counterpart linked to the same dam. The sample includes all high-skilled workers between 25 and 60 years old in the selected municipalities, excluding temporary workers and those employed in mining, agriculture, and the public sector. Panel (a) separates high-skilled workers based on race. Dark-skinned and indigenous workers are referred to as 'non-white,' and the other workers, including Asians, are referred to as 'white.' Panel (b) separates high-skilled workers based on gender at birth. Panel (c) separates high-skilled workers based on their highest level of education. Panel (d) separates high-skilled workers based on whether they occupy a managerial position or not. The diff-in-disc is estimated using log-linear Poisson regressions with municipality fixed-effects and a dummy for each year.