Distributional Effects of Environmental Policy across Workers: A General-Equilibrium Analysis

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Effects on jobs carry great weight in political debates, especially for environmental policy. Previous research on the impact of environmental policy on jobs, such as Hafstead and Williams (2018) and Hafstead, Williams, and Chen (2018), finds that environmental policy reallocates workers across industries with little to no net job loss. But while those papers looked at changes in the number of jobs in different industries, they didn't directly address the distribution of transitional labor market dynamics across workers. This paper extends those papers by classifying workers by their industry at the time of policy implementation ("initial industry") and analyzing how the change in unemployment rates varies by initial industry over time. When we track workers by their industry at time of policy implementation, we find significant differences in short-run labor-market effects (as measured by changes in unemployment rates, earnings, and unemployment durations) across a range of policies aimed at reducing energy-related carbon dioxide emissions. Unsurprisingly, we find that large negative impacts are concentrated among workers initially employed in a few carbon-intensive industries. Finally, we show that policy pre-announcement and policy phase-ins can meaningfully reduce the short-run negative employment impacts both at the aggregate level and for the most affected groups of workers.

Key Words: jobs, unemployment, environmental regulation, performance standard, emissions pricing

JEL Classification Numbers: Q58, Q52, H23, E24, J64

1. Introduction

Effects on jobs carry great weight in political debates, especially for environmental policy. One reason might be concerns about overall unemployment, and the welfare cost of that unemployment. But it seems more likely that these concerns are driven by distributional concerns. Even if policy has little or no overall net effect in the long run, with job losses in polluting industries offset by job gains in cleaner industries, there could still be substantial negative effects on workers in industries that lose jobs, in the form of higher unemployment and/or lower wages for those workers, during the transitional period. The magnitude of these transitional labor market effects will depend strongly on how readily workers can move to new firms and new industries in response to a policy shock.

This paper aims to model and measure those distributional effects by building off the work in Hafstead and Williams (2018) and Hafstead *et al.* (2018). It uses a multi-sector general-equilibrium model that incorporates key labor market features (especially search frictions in the labor market) that limit workers' movement to new jobs and new industries. This extends the model from Hafstead *et al*. (2018) by adding additional frictions that are relevant for transitional labor market dynamics: a search friction that differs for within-industry vs. cross-industry matches (implying that all else equal, an unemployed worker is more likely to find a new job in the same industry than one in a different industry) and sticky wages (implemented via staggered wage bargaining).[1] These frictions limit labor market adjustments to policy shocks and thus are important drivers of differential effects across workers from those policy shocks.

A few other very recent papers attempt to get at some of these same distributional issues. Aubert and Chiroleu-Assouline (2019) and Fernandez Intriago (2019) each use general-equilibrium search-friction models to study the distributional effects of environmental policy. But each of these papers uses a highly stylized two-sector model. And while these models provide many useful insights, it's not clear that such stylized and aggregated models can capture key distributional effects. Castellanos and Heutel (2019) use a more disaggregated model (11 sectors) with a more realistic calibration and more industry detail, but don't explicitly model search frictions. Instead, they use a reduced-form wage curve approach to model unemployment in each industry and consider two extremes for worker mobility: perfect mobility (workers can

[1] Both of these frictions were included separately as extensions to the stylized two-sector model in Hafstead and Williams (2018).

instantly and costlessly switch industries in response to a policy shock) and perfect immobility (workers can never switch industries).

Our paper makes three key contributions. The first is methodological: to our knowledge, this paper provides the first tractable general-equilibrium model with more than two sectors that incorporates frictions that differentially slow cross-sector movement of workers. Despite being relatively simple, this model generates a surprisingly rich pattern of dynamic effects from a policy shock. This type of model should be useful for examining labor market effects of a wide range of policies, beyond just environmental issues. Second, by tracking effects on different workers in that model, we can evaluate the distributional effects on workers that occur via changes in unemployment rates and wages caused by environmental policy and examine effects that mitigate or magnify differential outcomes across workers. Third, we compare how the distributional effects vary across different policy designs. In particular, we model how the distributional effects on workers will change if policy is either phased-in over time or pre-announced.

In this paper, we focus on three policies to reduce energy-related carbon dioxide emissions in the US: a power sector performance standard, power sector carbon tax, and an economy-wide carbon tax. When we track workers by their industry at the time of policy implementation, we find substantial heterogeneity in short-run labor market outcomes across workers following introduction of an unanticipated policy. Workers initially attached to carbon-intensive industries experience significant adverse impacts relative to workers in non-carbon-intensive industries: large short-run increases in unemployment rates, decreases in earnings, and increased unemployment spells in response to all three policies.

Our analysis suggests that both the size and duration of changes in short-run unemployment rates for particular worker groups depend both on the ease with which workers can switch industries and on how quickly wages can adjust to the new policy. However, we still find substantial divergence in labor market outcomes across worker groups across a range of alternative parameter assumptions. Finally, we show that environmental policies that are either pre-announced or phased-in can significantly reduce the negative short-run labor market impacts for all workers, but especially for workers initially employed in the most affected industries.

The next section of the paper describes the model and its calibration. Section 3 presents our central-case modeling results and examines how those results change in response to changes in key parameter assumptions. Section 4 considers approaches to mitigating the distributional effects, such as policy pre-announcements and phase-ins. Section 5 concludes and discusses caveats and key directions for future work.

2. Brief Model Description

Our model is an extension of Hafstead et al. (2018) and is an otherwise standard environmental CGE model of the US economy (with international trade) with a search-and-matching labor market friction. Beyond Hafstead et al. (2018), our model includes both industry switching frictions and staggered wage bargaining. These extensions affect the transition but not the steady state. Here, we include a brief model description with a focus on key differences from Hafstead et al. (2018).

Production

There are 22 private industries and a government sector (representing federal/state/local government). Each industry combines labor, energy inputs, and material inputs to produce a distinct good using a standard nested constant-elasticity-of-substitution (CES) production function. Table 1 provides a complete list of industries.[2]

[2] Government enterprises are considered a private industry and are separate from the public government sector. However, in Table 1 "Government (incl. enterprises)" aggregates government enterprises and the public sector together.

Table 1. Separation Rates and Labor Share by Industry

Industry	Separation rate	% of total labor compensation
Oil&gas extraction	4.6	0.16
Coal mining	4.6	0.04
Other mining	4.6	0.07
Mining support services	4.6	0.52
Electric power	3.2	0.66
Natural gas distribution	3.2	0.18
Petroleum refining and coal products	2.3	0.17
Water/sewage utilities	3.2	0.03
Agriculture	4.6	0.54
Construction	4.7	5.10
Durable manufacturing	2.0	5.85
Nondurable manufacturing (excl. refining)	2.3	2.95
Wholesale trade	2.4	4.66
Retail trade	4.7	4.95
Transportation and warehousing	3.2	3.17
Information	2.8	2.79
Finance, insurance, real estate (incl. housing)	2.3	8.37
Professional business services	5.2	18.34
Education and health	2.6	12.33
Leisure and hospitality	6.1	4.70
Other services	3.6	3.84
Government (incl. enterprises)	1.5	17.63

Each private industry is classified as either an energy industry (E) or a materials industry (M). Oil&gas extraction, Coal mining, Electric power, Natural gas distribution, and Petroleum refining and coal products are all classified as energy industries, and the remaining industries, including government enterprises, are classified as materials industries. Firms (or the government) choose inputs of energy and materials to minimize the unit cost of intermediate inputs as is standard in nested CES frameworks.[3]

Firms (or the government) begin each period with a stock of workers n_j and then decide whether to allocate workers to the production process l_j or to worker recruitment v_j. The total labor input is equal to number of the number of production workers times the hours per worker

[3] See Hafstead et al. (2018) for a complete description of the nested CES production function.

(and total recruitment effort is equal to the number of recruiters times the hours per worker). The outer nest of the production function is

$$y_j = f_j(h_j l_j, I_j) \quad (1)$$

where I_j denotes the aggregate intermediate input composite. Let $\overline{v}_j = v_j / n_j$ denote the recruiter ratio (the fraction of workers allocated to recruitment). Taking recruitment productivity as given, the firm chooses recruitment effort $\overline{v}_j$ and the overall level of intermediate inputs I_j to maximize the value of the firm. For each industry *j*, the value of the firm can be represented by the Bellman equation,

$$J(n_j) = \max_{I_j, \overline{v}_j \geq 0} \left\{ p_j^d f_j(h_j n_j(1-\overline{v}_j), I_j) - (1+\tau_P) h_j n_j w_j - \overline{p}_j^I I_j + E\left[QJ(n_j') \right] \right\}$$

subject to

$$n_j' = (1-\pi_j) n_j + \sum_i H_{ij} \overline{v}_j h_j n_j \ .$$

where p_j^d represents the producer price for the good produced by industry *j*, and τ_P represents employer payroll taxes. Recruiter productivity is denoted by H_{ij} and it represents the number of unemployed workers formerly employed in industry *i* that can be hired by a single industry *j* recruiter (the formula for H_{ij} is described below). Firms lose a fixed fraction of workers each period through an exogenous separation rate π_j and in the steady state total separations must equal new hires.[4] In the policy transition, firms (almost) always recruit workers and even a small change in recruitment effort could alter the number of workers employed in each period.[5] The public government sector also chooses recruitment effort and intermediate inputs to provide a fixed level of a public good at minimum cost.[6]

[4] The model holds total exogenous separations (layoffs plus voluntary quits/retirements) constant. Across the business cycle, overall separations are relatively constant; increased layoffs often lead to decreased voluntary separations; we anticipate a similar pattern in response to policy. However, this implies that our model will not be able to capture differential economic impacts of changes in the layoff/voluntary separation ratio.

[5] Firms are also allowed to increase separations (fire workers) above the exogenous separation rate if, with zero recruitment effort, the value of the firm at current employment levels is below zero. In our analysis, we find that increased separations are rare and only occur in particularly affected industries in the first month of the policy.

[6] See Hafstead et al. (2018) for a description of the public government sector problem.

Workers

The mass of workers is normalized to one, without loss of generality. Unemployed workers are identified by their previous employer *j* and employed workers are identified by their current industry *j*. Employed workers work h_j hours and receive an hourly wage w_j whereas unemployed workers work zero hours but receive unemployment compensation, b.[7] Wages and hours are bargained between firms and workers. As is standard in the search-and-matching literature, all workers are part of a representative household framework (see, for example, Merz 1995).[8] The household owns the firms and has access to state-contingent claims, B, where Q denotes the price of an Arrow security that delivers one unit of consumption in the subsequent period. As is also standard in both full-employment multisector CGE models and one-sector search-and-matching models, household utility is increasing in aggregate consumption, $\overline{C}$, and decreasing in hours worked. Here we use a separable utility function in aggregate consumption and hours,

$$U(\overline{C},h) = \log(\overline{C}) - \psi \frac{h^{1+\chi}}{1+\chi} \tag{2}$$

where ψ represents the labor disutility parameter and $(1/\chi)$ represents the Fritsch elasticity of labor supply. For simplicity, we assume that the disutility of labor does not vary across sectors.

Given the distribution of workers across industries and unemployment at the beginning of the period, the bargained levels of wages and hours, the current level of assets, and the probability of an unemployed worker *i* finding a job in industry *j* ϕ_{ij}, households choose aggregate consumption and future assets to maximize life-time discounted utility

$$V(B,u_i,n_j) = \max_{\overline{C},B'} \left\{ \sum_j U(\overline{C},h_j) + \sum_i U(\overline{C},0) + \beta E\left[V(B',u_i',n_j') \right] \right\} \tag{3}$$

subject to the budget constraint,

$$\overline{p}\overline{C} + QB' \leq \sum_j (1-\tau_L) n_j w_j h_j + \sum_i \overline{p}b + B + T \tag{4}$$

[7] In our policy simulations, unemployment compensation is held fixed in real terms such that any policy-induced change in employment is not due to changes in unemployment compensation.

[8] This framework assumes full insurance across workers such that the marginal utility of consumption is constant across workers regardless of past or current employment status.

and the law of motion for unemployment and employment by sector

$$n'_j = (1-\pi_j)n_j + \sum_i u_i \phi_{ij}, \ \forall\ j \quad (5)$$

$$u'_i = (1-\sum_j \phi_{ij})u_i + \pi_i n_i, \ \forall\ i \quad (6)$$

$$\sum_j n_j + \sum_i u_i = 1 \quad (7)$$

where β is the discount factor, τ_L is the tax rate on labor income, T is government lump-sum transfers (taxes if negative), and $\overline{p}$ is the unit cost of aggregate consumption.[9]

Generalized Matching Function

To incorporate industry switching frictions, we introduce a generalized matching function as in Hafstead and Williams (2018) such that the probability a worker finds a job in any given industry is a function of the worker's previous job experience; such an assumption prevents workers from easily moving industries during the transition (from a regulated to an unregulated industry, for example). The matching function is given by

$$m_{ij} = \mu_j v_j h_j u_i \left[\xi \left(\sum_k v_k h_k \right)^{-\gamma_j} \left(\sum_k u_k \right)^{\gamma_j - 1} + (1-\xi)\left(v_j h_j\right)^{-\gamma_j} \left(u_i\right)^{\gamma_j - 1} \delta_{ij} \right] \quad (8)$$

where ξ is a parameter that controls the degree of matching across sectors (for $\xi = 0$, a worker last employed in industry *i* can only match to industry *i*, for $\xi = 1$, matching is independent of the industry in which a worker was last employed, and in between, the number of cross-industry matches is proportional to ξ), and δ_{ij} is the Kronecker delta (equal to one if $i = j$ and zero otherwise). The parameters μ_j and γ_j are the standard match efficiency and elasticity parameters, respectively. If $\xi = 1$, the matching function is identical to the multisector version of a standard matching function (see, for example, Shimer, 2010).

In equilibrium, the number of matches must equal both the recruiting effort times recruiting productivity, $m_{ij} = (v_j h_j)H_{ij}$, and the number of workers searching times the probability a worker finds a job, $m_{ij} = u_i \phi_{ij}$. Using the matching function in equation (7), we can then write recruiter productivity and the job finding probability as

[9] Again, see Hafstead et al. (2018) for details.

$$H_{ij} = \mu_j \left[\xi(\bar{\theta})^{-\gamma_j} + (1-\xi)\theta_{ij}^{1-\gamma_j}\delta_{ij} \right] \tag{9}$$

$$\phi_{ij} = \mu_j \left[\xi\theta_j\bar{\theta}^{-\gamma_j} + (1-\xi)\theta_{ij}^{1-\gamma}\delta_{ij} \right] \tag{10}$$

where $\theta_{ij} = (v_j h_j)/u_i$ is the ratio of recruitment effort in industry *j* relative to unemployed workers from industry *i*, $\theta_j = (v_j h_j)/\sum_i u_i$ is the ratio of recruitment effort in industry *j* relative to total unemployed workers, and $\bar{\theta} = \sum_j \theta_j$ is the ratio of total recruitment effort to total unemployed workers. As in the more common matching function, the ratio variables reflect the tightness of each labor market: hiring is easier if overall recruitment effort falls or if there are more unemployed workers searching for jobs.

Staggered Wage Bargaining

In the long run, we assume that wages are fully flexible: wages and hours are effectively renegotiated each period. As is common in the search and matching literature, we assume Nash bargaining between workers and firms.[10] Under this bargaining assumption, hours are set to maximize the surplus created by the match (the value of the match to the employer plus the value of the match to the employee) by setting the marginal disutility of hours worked by the worker equal to the marginal benefit to the firm of an additional hour of work; wages are then set to split the surplus between the worker and firm according to the employer's bargaining power.[11]

In the short run, however, wages are unlikely to be fully flexible and/or may not be renegotiated in each period. Following an extension in Hafstead and Williams (2018), we incorporate the Gertler and Trigari (2009) staggered wage bargaining model; in each period, only a fraction of firms ($1-\rho$) within an industry may renegotiate wages. We follow Gertler and Trigari and assume that all workers at a given firm receive the same wage. Given the Poisson

[10] We assume that unemployed workers that are matched with industry j and do not accept the bargained wages become industry j unemployed workers, despite never working for the industry. In equilibrium, all matches lead to employment and this assumption simplifies the math determining the worker's outside option in the Nash bargaining problem such that we can use the standard Nash bargaining equations as in Hafstead and Williams (2018) or Hafstead et al. (2018).

[11] See Hafstead and Williams (2018) or Hafstead et al. (2018) for a complete description of the bargaining problem.

adjustment and common-within-firm wage assumption, we can write the average wage in each sector as a function of an optimal target wage (which takes into consideration that the wage may be fixed for a lengthy period) and the average wage in the previous period.[12]

Data

Data on input use by sector, consumption by households, and labor input by sector are aggregated from the 2015 Bureau of Economic Analysis (BEA) Make and Use Tables from the Annual Industry Accounts.[13] Industry-specific separation rates are derived by averaging monthly total separation rates for each industry grouping in the Job Opening and Labor Turnover Survey from the Bureau of Labor Statistics. Table 1 displays these industry-specific separation rates. We calibrate energy-related carbon dioxide emissions coefficients to match emissions data from the Energy Information Administration (EIA).

Standard CGE Parameter Calibration

The time period in the model is one month. The discount factor is calibrated to be consistent with an annual interest rate of 4 percent. The Frisch elasticity of labor supply is set equal to 1. As discussed in Hall and Milgrom (2008), this represents a middle ground between estimates found for middle-aged men and other single-earner families (0.7) and higher elasticities found for young men and married women. The tax on labor is set to 0.31, a rate that approximates the average marginal combined federal and state income tax rate plus the employee payroll tax contribution. The payroll tax is set to 0.06, representing the employer share of payroll taxes. We apply an elasticity of substitution across consumption goods to be a conservative 0.75. Elasticities of substitution in production are taken from Jorgenson and Wilcoxen (1996).

[12] All workers at a firm receive the same wage; if renegotiations take place, both new workers and incumbents receive the same wage. Hours are still fully flexible in this framework.

[13] https://www.bea.gov/industry/io_annual.htm
In some cases, the level of aggregation in the two models in this paper do not correspond one to one with the summary-level industry aggregation in the BEA annual data. In these cases, the detailed-level industry aggregation in the 2007 Benchmark Accounts is used to disaggregate the summary-level data. Inputs of Oil&Gas extraction and Coal mining are revised to be consistent with EIA data on energy inputs and prices by industry.

Search and Matching Parameters Calibration

For the search and matching labor market parameters, we follow Hafstead and Williams (2018) by assuming relatively standard search-friction parameters. We start by using a steady state unemployment rate of 5 percent and a within-industry recruiter productivity of 25 (when unemployed workers *j* match with its previous industry *j*), and we fix hours in the public sector such that employees spend one-third of their time working.[14] Following Hall and Milgrom (2008), we set the match elasticity equal to 0.5, and following Shimer (2010), we set the Nash bargaining parameter equal to 0.5.[15]

Conditional on these assumptions, we then implement a calibration procedure to solve for the disutility of work parameter, the level of unemployment benefits, the match efficiency parameter by sector, and hours per worker in the private sector that are consistent with the model equations and asymmetric separation rates across sectors.[16]

For the industry switching friction, we rely on analysis by two EPA economists, Alex Marten and Andrew Schreiber, who used data from the Current Population Survey to estimate industry-to-industry transition probabilities. This data implies that industry retention rates are low: the share of workers who change jobs but remain in the same industry varies from 6 percent (Management of Companies and Enterprises) to 58 percent (Agriculture, Forestry, Fishing, and Hunting). We choose the friction parameter ξ such that 33 percent of unemployed workers are reemployed in the same industry they previously worked in.

For the staggered wage parameter [rho], there is no systematic evidence on how often wages are adjusted and therefore we follow Gertler and Trigari and set the wage renegotiation parameter such that wages are renegotiated once every 9 months, on average.

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[14] Silva and Toledo (2009) estimate that the cost of recruiting a single worker is equal to approximately 12 percent of a worker's monthly wage. Adjusting for hours (one-third), this implies that one recruiter can hire 25/3 workers per month. The generalized matching function parameter determines steady state cross-industry recruitment productivity as a function of the within industry recruitment productivity.

[15] In models without taxes, setting the bargaining parameter equal to the match elasticity ensures the Hosios condition such that the equilibrium level of unemployment is efficient from the social planner's perspective. However, in the presence of preexisting taxes on labor, the Hosios condition does not hold even when these parameters are equal.

[16] This calibration strategy implies that hours per worker vary across sectors because of differences in marginal products of labor and that the marginal value of employment in each sector varies across sectors.

3. Simulating the Distributional Impacts of Environmental Policy

3.1 Environmental Regulations

In this analysis, we consider three policies designed to reduce carbon dioxide emissions. Two of the policies apply to electric power sector CO_2 emissions only and one policy applies to all domestic CO_2 emissions. In the electric power sector, we consider both a tradable performance standard and a $25 carbon tax (in $2015). By design, the performance standard stringency is set to deliver the same long-run emissions reductions in the power sector (40 percent below business-as-usual). And because the performance standard is equivalent to a tax on power sector emissions and subsidy on electricity generation, as shown in Goulder et al. (2016), a comparison of the performance standard and carbon tax on power sector emissions across workers may be particularly revealing about how policy design impacts transitional labor market dynamics across workers.

We also consider a $25 economy-wide carbon tax on energy-related CO_2 emissions, similar to the taxes considered in Hafstead et al. (2018). A number of proposals call for an economy-wide price on carbon dioxide emissions, including the Climate Leadership Council's Baker-Shultz Carbon Dividend Plan, the Whitehouse-Schatz American Opportunity Fee Act, the bipartisan Energy Innovation and Carbon Dividend Act, and the Republican MARKET CHOICE Act. These proposals indicate a growing interest in an economy-wide carbon tax, but vary widely in the starting price level and rate of change over time. For illustrative purposes, we have chosen to match the tax rates in our power sector-only and economy-wide carbon tax to compare how the scope of carbon pricing policies impact the transitional labor market dynamics across workers.[17] Revenue from the policy is recycled to households through lower labor income taxes.

3.2 Transitional Labor Market Dynamics Across Workers

In this model, workers are identical except for which industry they're employed in (or, for unemployed workers, which industry they were most recently employed in). Therefore, to look at differential effects across workers, we group workers based on which industry they were

[17] Many of the carbon tax proposals contain elements not modeled in this analysis. For example, the Baker-Shultz Carbon Dividend Plan includes border adjustments and a reduction in regulations, neither of which are included in this analysis.

initially attached to: that is which industry they were employed in (or unemployed after working in) at the time of the policy shock (when the policy first takes effect, or, in the case of a preannounced policy, when it is announced). We then track these workers over time, and compare how various job market outcomes differ across workers based on their "initial industry".

Let u_{ki} denote the mass of workers that were unemployed workers in initial industry *k* and are currently unemployed workers in industry *i*. If , then such a worker must have found a job in industry *i* at some point after policy implementation and then lost that job in a subsequent period. Likewise, let n_{kj} denote the mass of workers that were employed in initial industry *k* in the period of policy implementation and are currently employed in industry *j*. The laws of motion for u_{ki} and n_{kj} must follow

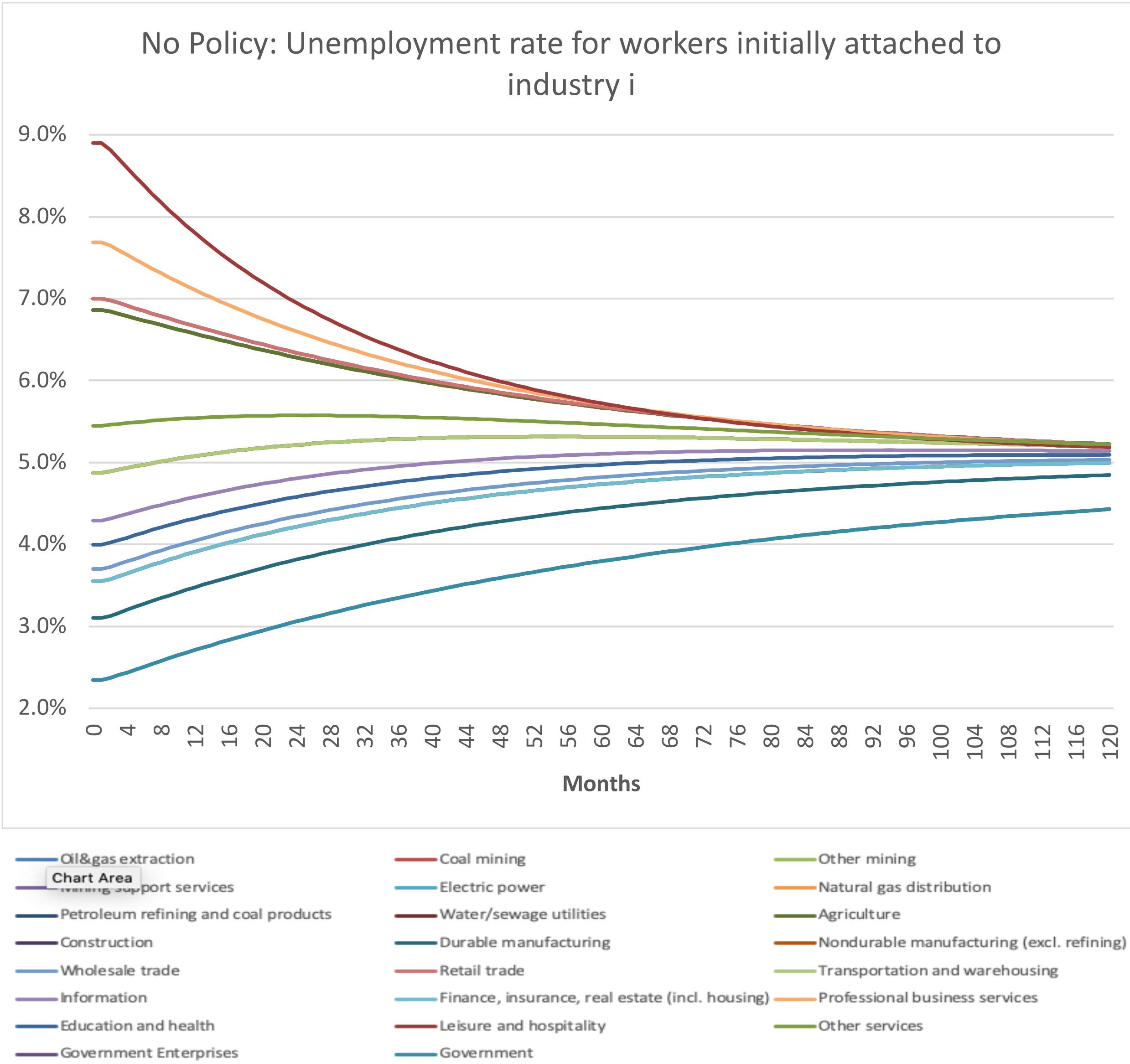
$$u'_{ki} = u_{ki} - \sum_j u_{ki}\phi_{ij} + \pi_i n_{ki} \tag{11}$$

$$n'_{kj} = (1-\pi_j)n_{kj} + \sum_i u_{ki}\phi_{ij} \tag{12}$$

For this analysis, we are interested in how policy-induced changes in the unemployment rate, after-tax earnings, and job-finding probabilities vary across workers based on their initial industry *k*. The unemployment rate for initial industry *k* workers is given by $\overline{u}_k = \sum_i u_{ki} / \left(\sum_i u_{ki} + \sum_j n_{kj} \right)$, average after-tax earnings for initial industry *k* workers are given by $\overline{earn}_k = \sum_j (1-\tau_L) n_{kj} w_j h_j + \sum_i u_{ki} \overline{p} b$, and the job-finding probability is . In the long run, all workers will be evenly spread across industries, regardless of their initial industry. Thus the levels of these labor market variables must eventually be equal across initial industries, and so must any policy-induced changes.[18] However, these labor market outcomes differ widely by initial industry in the short-run, and policy-induced changes in these outcomes will likely also differ dramatically.

[18] Because our model assumes workers are all-else equal besides industry status, the long-run steady state implies a stable distribution of workers across industry and employment such that all worker groups, by initial industry or some other partition, will have the same long-run labor market outcomes.

Figure 1: Unemployment Rate by Initial Industry, Reference (no policy) Case



To help illustrate the concept of these initial-industry comparisons, and to preview some of the dynamics at work, Figure 1 presents the unemployment rate by initial industry for the reference case: that is, in the absence of any policy changes.

Note that the economy is in a steady state for this entire figure. But unemployment rates differ across workers according to their initial industry: workers initially in industries with a high separation rate have relatively high unemployment, and workers initially in industries with a low separation rate have relatively low unemployment. This difference shows up most strongly in period 0 on the figure. If, however, we were to report unemployment rates based on workers' current industry, the lines in this no-policy case would all be flat at that period 0 level.

But keep in mind that we're not doing that: instead, we're tracking workers based on their initial industry. Over time, workers migrate across industries: each time a worker separates from a job, there's some chance that worker's next job will be in a different industry. Thus, over time, unemployment rates converge, with the rate falling for workers initially in a high-turnover industry and rising for workers initially in a low-turnover industry.

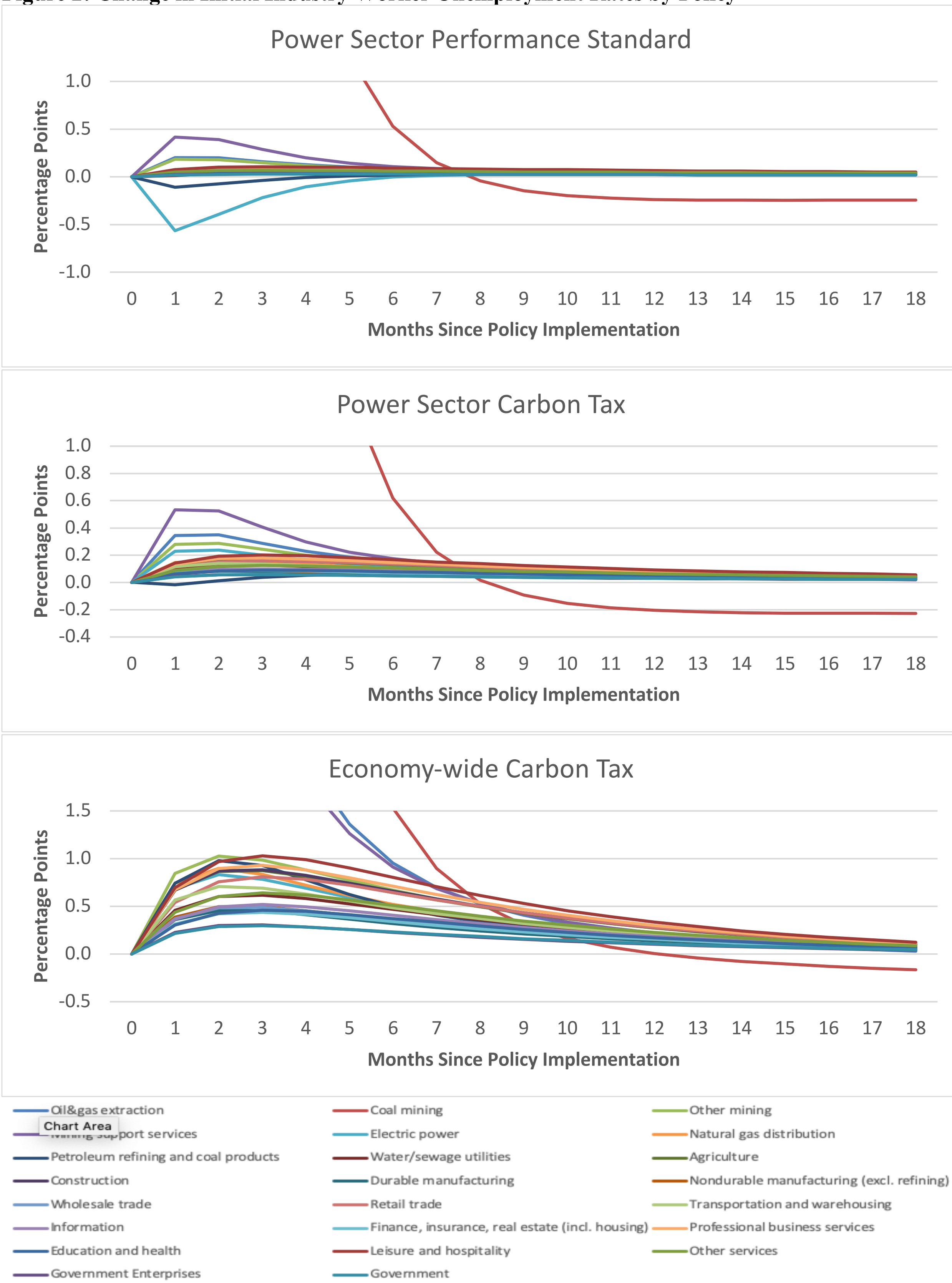
Interestingly, for workers whose initial industry falls in the middle, unemployment rises and then falls. This is because the higher-turnover industries are doing a disproportionate amount of hiring, and thus a newly unemployed worker is disproportionately likely to find a job in a high-turnover industry, and thus unemployment rates for workers who recently switched jobs are higher than the average for the whole economy. This is an interesting dynamic, picking up (in a very limited way) that some jobs have higher turnover than others, and thus that an unemployed worker might go through several high-turnover jobs before eventually settling down in a low-turnover job.

Understanding patterns in this figure is useful for understanding some of the results later. When we analyze the effects of policy, we look at the difference between the path of a labor-market outcome (e.g., unemployment rate) with a policy shock and its path with no policy change. It's helpful to keep in mind that even in that no-policy case, these outcomes are changing over time as workers migrate among industries.

We now move on to simulate policy changes. Figure 2 displays the change in unemployment rates by initial industry by policy when the policy shock is unanticipated. Across all three policies, there is considerable heterogeneity in the short-run unemployment rates across workers (categorized by their industry classification at the time of policy implementation) but, as expected, the change in unemployment rates across workers converges over time.

Each policy dramatically reduces coal use in the electric power sector and, as a result, coal mining workers (at time of policy implementation) face large increases in unemployment regardless of policy: the unemployment rate of these workers increases from 5 percent to 42-43 percent in the first period of the policy through additional separations (the figures are truncated to prevent the coal mining results from dominating the figures).

Figure 2: Change in Initial Industry Worker Unemployment Rates by Policy

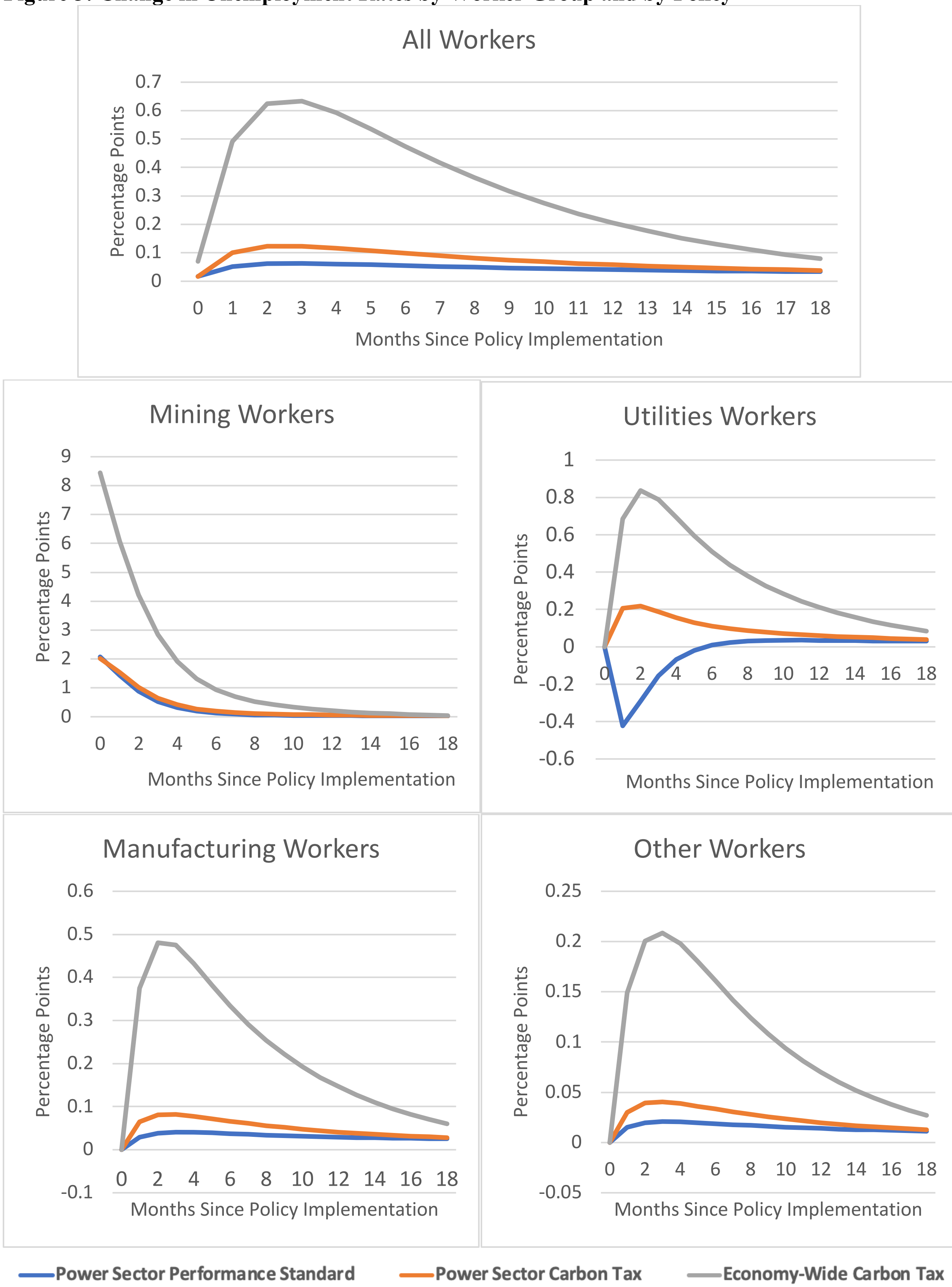


Interestingly, the change in the unemployment rate becomes negative for a significant period of time starting 8 – 12 months after the policy shock for these same workers. To understand this result, remember that even in the no-policy case, unemployment changes over time for workers grouped by initial industry. Coal mining is a high-turnover sector, and thus in the absence of policy, unemployment for workers initially in coal mining starts high and gradually falls over time as those workers migrate to lower-turnover sectors. The simulated policies all cause substantial near-term job loss, but that job loss greatly accelerates the migration of coal miners to lower-turnover sectors, so in the medium term, unemployment for workers initially in coal mining is actually lower than it would have been in the absence of policy. Of course, this assumes that former coal workers are equally productive in these low turnover sectors (i.e. government) as other workers, and introducing heterogeneity in worker skills may mitigate this channel of reallocation. Thus, to some extent, this exact result may be an artifact of some of the simplifying assumptions in this stylized model. Nonetheless, it seems plausible that while substantial job loss in coal mining would have serious costs for coal miners in the short run, accelerating their movement to other sectors could make them better off some time in the future.

Given the large heterogeneity across initial industry worker groups in Figure 2, we group initial industry workers into four main groups: workers initially in mining industries (oil&gas extraction, coal mining, other mining, and mining services), utility industries (electric power, natural gas distribution, water/sewage), manufacturing industries (petroleum refining, durable and nondurable manufacturing) and other industries (including the public sector).

Figure 3 reports the change in unemployment rates across all workers and for each of these four worker groups. There are substantial differences in the change in unemployment rate by worker group by policy. Unsurprisingly, the largest short-run impacts for each worker type are under the economy-wide carbon tax (though this policy also generates the largest emissions reductions). In particular, the economy-wide carbon tax generates much larger increases in unemployment rates for the group of workers in mining industries at the beginning of the policy as oil&gas extraction and mining services workers large increases in unemployment, though still

Figure 3: Change in Unemployment Rates by Worker Group and by Policy



much smaller than the impacts on coal miners.[19] Utilities workers also experience much larger impacts under the economy-wide carbon tax due to impacts on workers initially employed in the natural gas distribution industry. And though the changes are still small in absolute terms, the economy-wide carbon tax also implies the largest change in unemployment rates for the manufacturing and other worker groups, because this tax covers emissions from all fossil fuel uses.

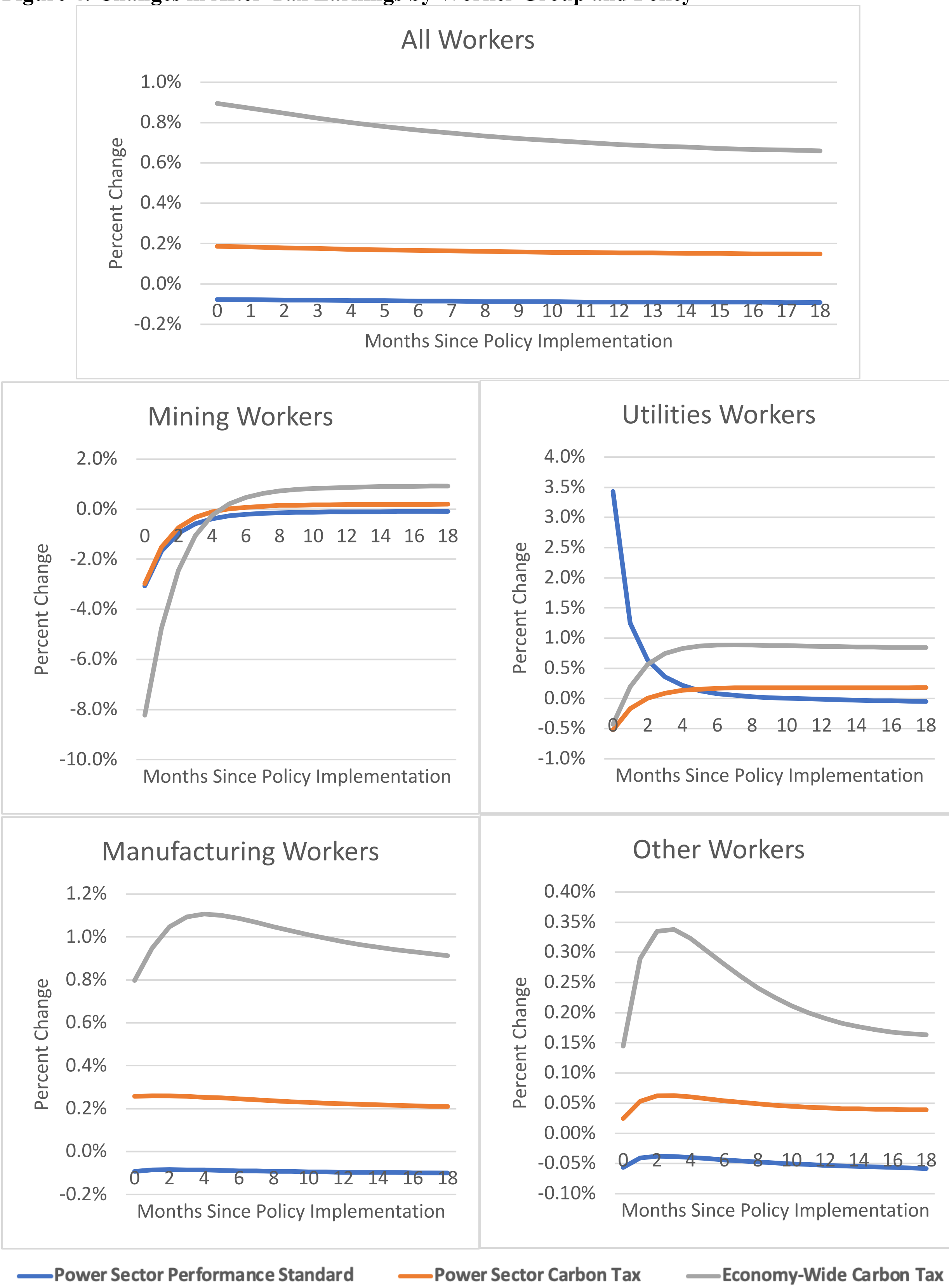
Comparing the power sector policies, mining workers experience approximately the same changes in unemployment rates but utility workers actually experience a decrease in unemployment rates under a performance standard. As Goulder et al. (2016) and others have shown, a performance standard is equivalent to a revenue-neutral combination of a tax on emissions and a subsidy to output. This subsidy drives demand for labor in the power sector and due to industry switching frictions the new hires are largely the unemployed workers who were previously employed in that industry. A performance standard also leads to smaller overall increases in the price of electricity (again, see Goulder et al, 2016) so it raises costs less for electricity-intensive industries. As a result the change in unemployment rates for workers in manufacturing or other industries is smaller under the performance standard than under the equivalent power sector carbon tax, due to smaller changes in labor demand in those sectors.

In our search-CGE model, workers are all part of a single representative household (implying full insurance across workers) and therefore we cannot simply use utility (or standard welfare measures) as a measure of differences across worker groups. As a proxy for welfare, however, we can calculate how each worker group's earnings (earnings from work plus unemployment benefits) change in response to the policy.[20] Figure 4 displays the change in total earnings by each worker group relative to no policy for all three environmental policies over time. The policies induce sharp changes in earnings across worker groups in the short-run.

[19] Oil&gas extraction and mining services unemployment rates increase by 9.7 and 6.7 percentage points, respectively, as a result of a decrease in demand for these fossil fuels and associated drilling services due to the carbon price on non-electric power fuel use. Alternative assumptions about world oil or gas markets may lead to different outcomes for these worker groups.

[20] Note that this measure will overstate the value of being unemployed (and thus the loss from unemployment), because it captures the earnings from working, but not the disutility of work. We plan to consider a more complete welfare measure in future versions of this paper.

Figure 4: Changes in After-Tax Earnings by Worker Group and Policy



There are a number of mechanisms that influence total earnings by worker group. First, unemployment benefits are only about 40 percent of average earnings in the model; substantial shifts to unemployment will decrease overall earnings for the group. Second, changes in labor taxes will impact after-tax earnings for all employed workers regardless of industry. Finally, our staggered wage bargaining determines when wages can adjust to reflect changes in marginal productivity and overall labor market conditions.

For the performance standard, earnings decline for mining workers due to the rise in unemployment for this group, and increase for utilities workers due to their drop in unemployment. Earnings drop in other sectors due to the increase in labor taxes to balance the government budget. The net effect on after-tax earnings for all workers is also negative: the increase in utilities isn't enough to offset the losses elsewhere.

Under the carbon tax policies, shifts to unemployment cause initial declines in earnings (relative to no policy) in the mining and utilities worker groups but over time earnings increase due to the labor tax cuts and the medium-term reduction in unemployment caused by accelerated migration of coal miners to lower turnover sectors (as discussed earlier). These earnings increases are larger under the economy-wide policy, because the effects driving them (labor tax cuts and accelerated migration out of coal mining) are larger. In the manufacturing and other worker groups, earnings increase immediately due to the tax cuts, but the change in earnings begins to fall as wages are renegotiated downward.

Changes in unemployment rates across worker groups are driven by changes in the job-finding probability for each worker group (apart from the first period of the policy when increased separations can occur).[21] Figure 5 displays the job-finding probabilities across worker groups for each policy. Generally, job-finding probabilities drop significantly in the first period of the policy and then slowly increase over time. Comparing across policies, the performance standard reduces job-finding probabilities by less than the power-sector carbon tax (except for utilities workers, whose job-finding probability increases under the performance standard). The economy-wide carbon tax reduces job-finding probabilities by much more than the power-sector carbon tax. Comparing across worker groups, job-finding probabilities decline the most for mining workers; other workers have the smallest decline in job-finding probabilities.

[21] Coal mining workers experience increased separations (i.e., layoffs) under all three policies. Oil&gas extraction and mining services workers experience increased separation under the economy-wide carbon tax.

Figure 5: Job-Finding Probabilities by Worker Group and Policy

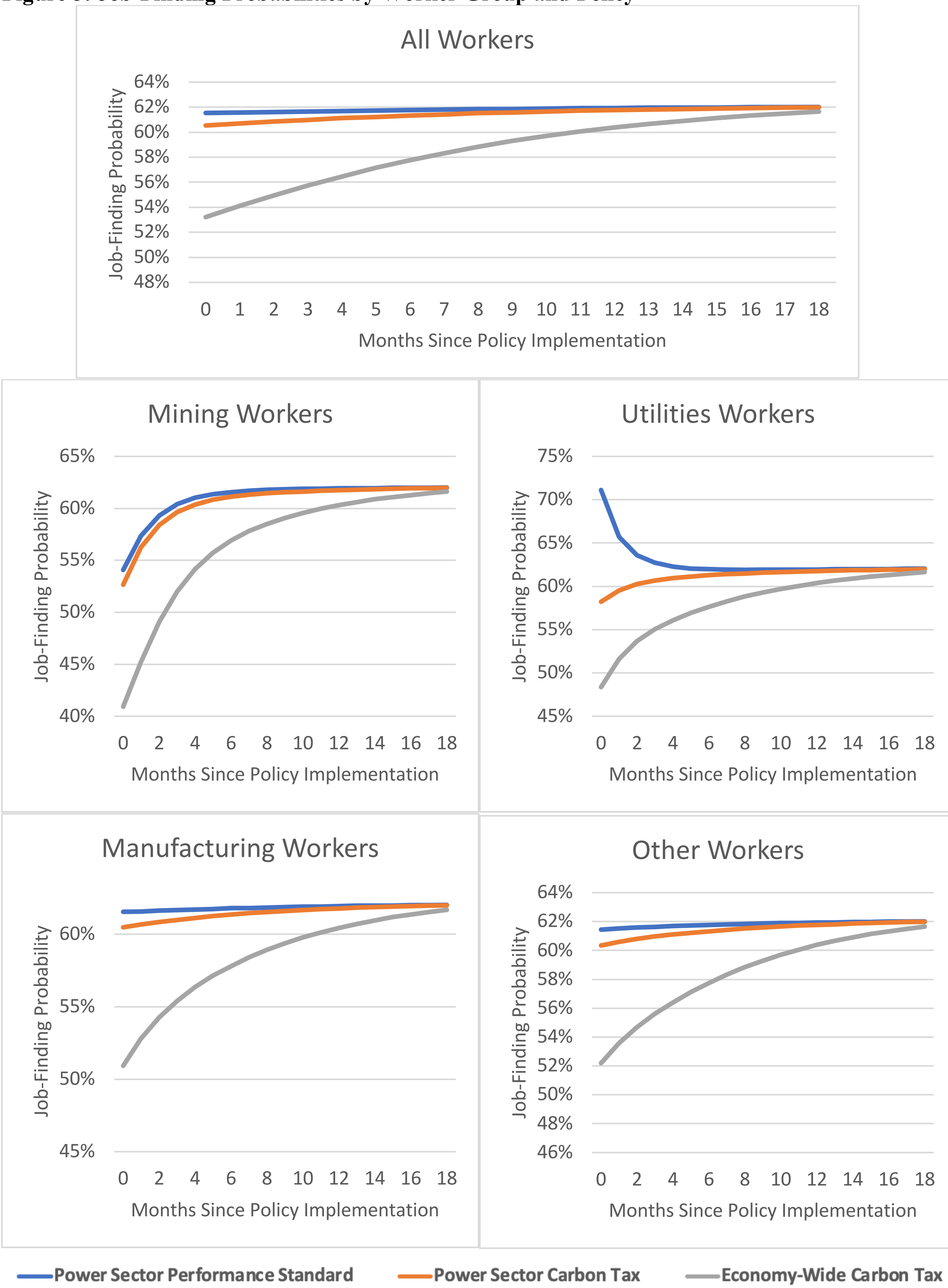


Table 2: Unemployment Durations by Worker Group and Policy for Workers Unemployed in the First Period of Policy

Performance Standard	Average Unemployment Spell (Months)	Fraction of Unemployment Spells 6 Months or Longer
All Workers	1.62	0.8%
Mining	1.79	1.2%
Utilities	1.45	0.5%
Manufacturing	1.62	0.8%
Other	1.62	0.8%
Power Sector Carbon Tax		
All Workers	1.65	0.9%
Mining	1.82	1.4%
Utilities	1.70	1.0%
Manufacturing	1.65	0.9%
Other	1.65	0.9%
Economy-wide Carbon Tax		
All Workers	1.85	1.9%
Mining	2.22	3.6%
Utilities	1.97	2.3%
Manufacturing	1.91	2.1%
Other	1.88	1.9%

The job-finding probability also determines how long workers are expected to be unemployed. Using the job-finding probabilities by worker groups, we can determine how environmental policy affects the duration of unemployment spells. In the no-policy steady state, a monthly job-finding probability of 62.4 percent for all workers implies that the average unemployment spell is about 1.6 months and about 0.75 percent of all unemployment spells last 6 months or more. Table 2 reports average unemployment spells and the fraction of spells that last 6 months or more for workers who become unemployed in the first period of the policy.[22] These results show that not only do worker groups experience different unemployment rates, but unemployment spell durations for workers who become unemployed in the first period of the

[22] These results hold only for newly unemployed workers in the first period of the policy. As job-finding rates increase over time, the average spell and fraction of long unemployment spells will decrease for workers who become unemployed in subsequent periods for each worker group.

policy vary by worker group. The change in average unemployment spell and fraction of long unemployment spells is relatively small for non-mining workers under the power sector performance standard and carbon tax policies, but there are some relatively large increases in unemployment duration for these worker groups under the economy-wide carbon tax. Mining workers who become unemployed in the first period of the policy (which includes coal miners who experience layoffs), experience much longer unemployment durations than other workers.

3.4 Sensitivity Analysis

The size and duration of short-run differences in unemployment rates across workers will depend on the ease with which workers can change industries and magnitude of cross-industry reallocation caused by a policy. The industry switching friction parameter is the key parameter in our model that determines the ease in which workers can change industries. In our central calibration, as discussed previously, we set the parameter such that 33 percent of unemployed workers find their next job in the same industry where they were previously employed. Here we consider increasing or reducing this industry switching parameter, such that 52 percent or 14 percent of unemployed workers find their next job in the same industry.

Reallocation of workers across industries is also a function of the wage adjustment process. If wages are fully flexible, then a policy-induced drop in wages encourages hiring in non-carbon-intensive industries. If wages are not fully flexible (as in our staggered wage bargaining model), then these non-carbon-intensive industries will be slower to absorb workers from carbon-intensive industries. To test the importance of short-run wage stickiness on the short-run differences in unemployment rates across worker groups, we reset the wage renegotiation parameter such that the average worker's wage changes every 4.5 months (less sticky) or 18 months (more sticky).

Figures 6-8 demonstrate how these changes in parameter values affect of our results for changes in unemployment rates across workers for the power sector performance standard, power sector carbon tax, and economy-wide carbon tax, respectively. Both parameters play a key role in determining the size and duration of unemployment changes for a particular worker group, but the change in the unemployment rate still differs widely across worker groups under each of the alternative parameter specifications.

Figure 6: Change in Unemployment Rates, Sensitivity Analysis, Power Sector Performance Standard

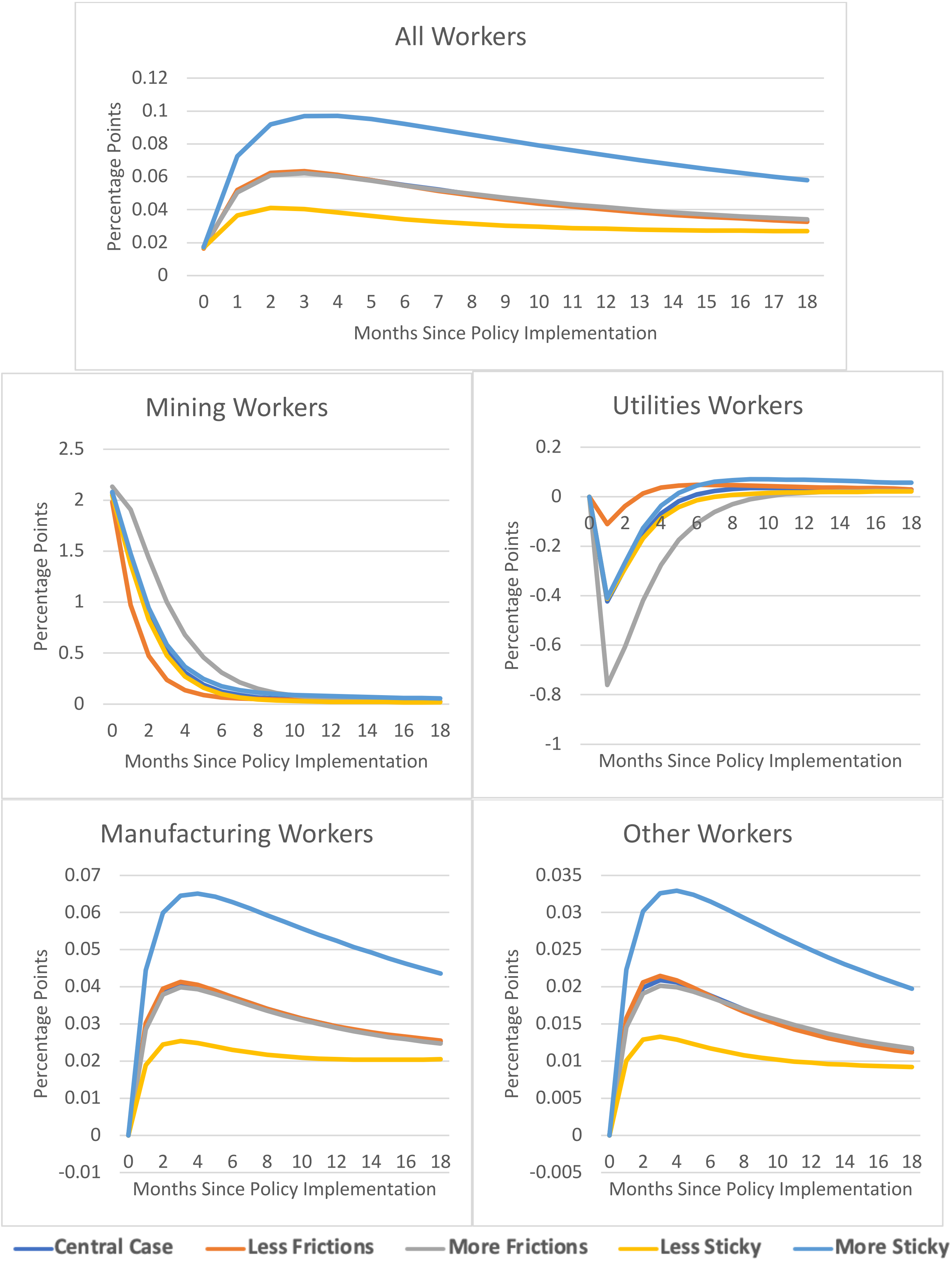


Figure 7: Change in Unemployment Rates, Sensitivity Analysis, Power Sector Carbon Tax

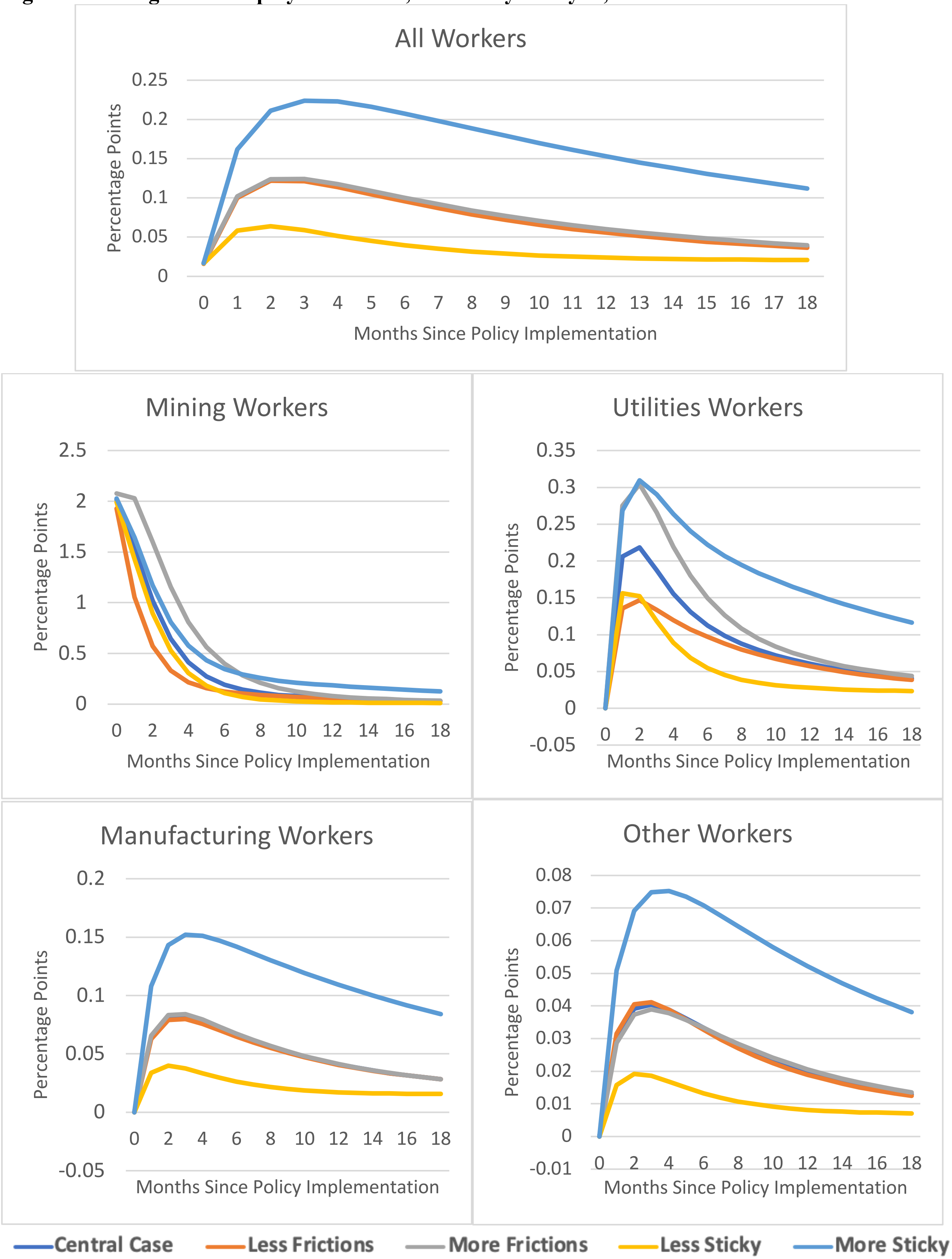
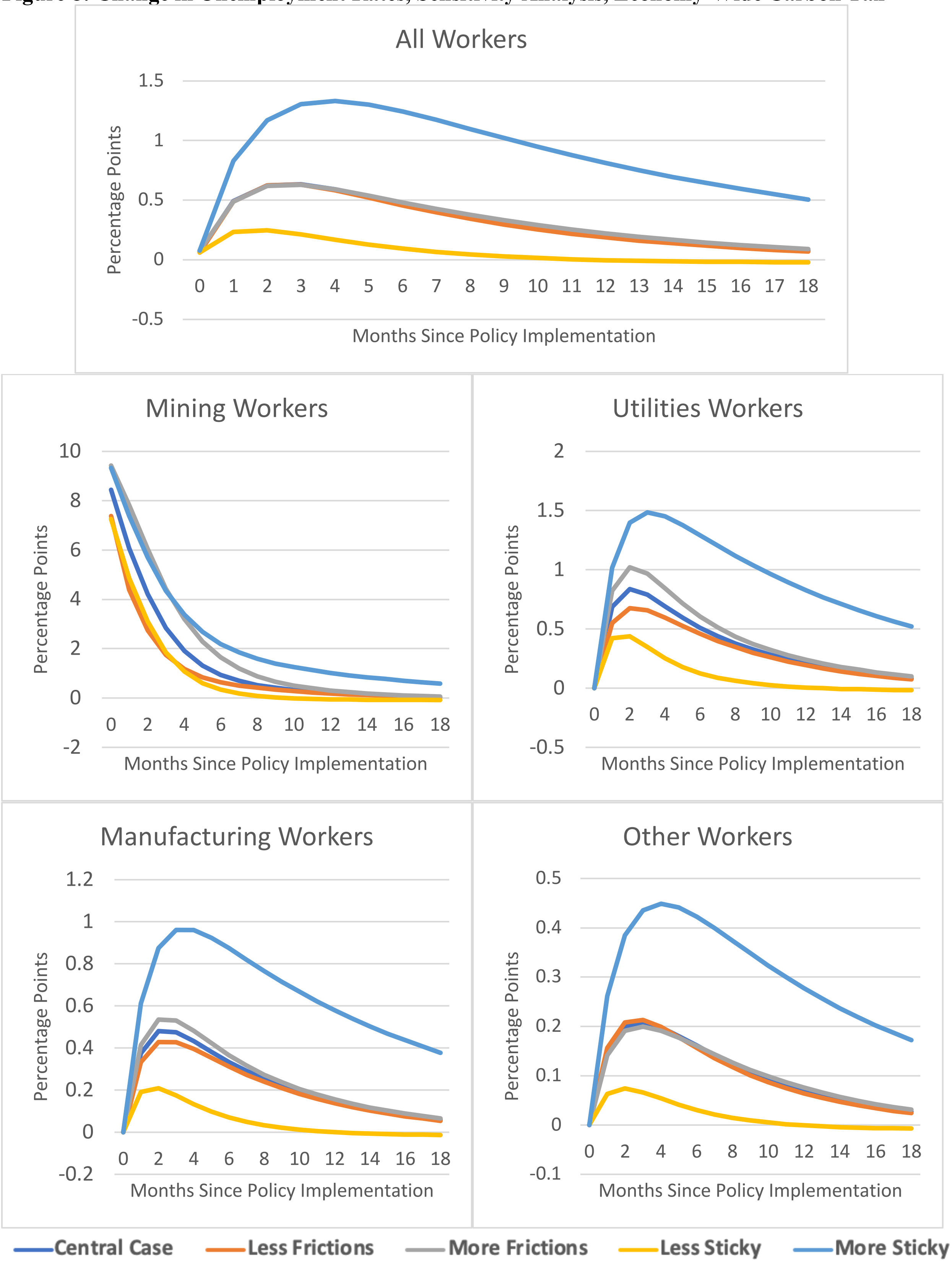


Figure 8: Change in Unemployment Rates, Sensitivity Analysis, Economy-Wide Carbon Tax



The industry switching friction is not particularly important in determining the unemployment rate across all workers or for workers that are not initially employed in mining, utilities, or manufacturing. However, industry switching frictions do play a role in determining the size and duration of the change in unemployment rates for workers initially in mining and utilities. In particular, the switching friction determines both the size and duration of unemployment changes for utilities workers under all three policies. In contrast, for mining workers, the friction is largely important only for the duration of changes in unemployment rates – perhaps because the near-term increase in unemployment rates for mining workers is largely driven by increased separations (i.e., layoffs) rather than lower job-finding rates.

Wage stickiness, on the other hand, is fundamentally important to both the size and duration of unemployment rates for all worker groups, especially those whose initial industries are relatively clean (Other). And because a vast majority of workers are employed in Other industries, the pattern of the changes in the overall unemployment rate across alternative parameter values largely mirror the pattern of changes in the unemployment rate of the Other worker group. Further, the wage stickiness parameter fundamentally determines if the change in the overall unemployment rate is trivial and short-lived or large and sustained, especially for the economy-wide carbon tax.

4. Mitigating Adverse Short-Term Labor Market Effects

The policies analyzed in section 3 are unanticipated policy shocks that take full effect immediately, thus forcing adjustments to occur relatively quickly. If these policies were phased-in or pre-announced, forward-looking firms could spread out those adjustments over time, potentially mitigating the adverse short-run labor market impacts. To investigate this hypothesis, we consider two policy alternatives. First, we consider a policy that is pre-announced six months prior to taking effect; in analyzing this policy we group workers by their initial industry in the period the policy is announced.[23] Second, we consider policies that are phased-in linearly over a twelve-month period.[24]

Figures 9-11 display the change in unemployment rates by worker groups across the three policies. Under pre-announced policies, firms anticipate the policy and begin to reduce their hiring rates immediately, reducing the pressure for firms to increase separations or dramatically reduce hiring when the policy is implemented.[25] Most significantly, the policy-induced increase in the unemployment rate for mining workers falls dramatically when the policy is pre-announced by six months. And more generally, while there is still significant heterogeneity in short-run changes in unemployment rates across different worker groups, pre-announcement policies greatly damp the effects on unemployment rates for all worker groups.

Under the policy phase-in scenarios, a slow ramp-up in the tax rate significantly reduces (but doesn't eliminate) increased separations in the first period of the policy for mining workers and causes a smaller drop in job-finding probabilities for workers from carbon-intensive industries.[26] As a result, short-run changes in unemployment rates are smaller for workers from mining, utilities, and manufacturing. Changes in short-run unemployment rates are also smaller for other workers: less competition within the labor market implies workers who become unemployed from those industries have a higher probability of finding a job.

[23] In the current version of the model, policy-induced changes in labor taxes occur when the policy is announced, not when the policy is actually implemented. This implies carbon taxes with labor tax cuts introduce the tax cuts six months prior to the implementation of the tax. This could represent a realistic policy: for example, under the British Columbia carbon tax, cuts in other taxes took effect several months before the carbon tax itself.

[24] For example, the carbon taxes increase by $2.08 per month ($25 divided by 12) until they reach $25.

[25] The coal mining industry still increases separations at the time of policy implementation under the pre-announced policies, but the level of increased separations falls dramatically.

[26] The current version of this paper does not include a power sector performance standard policy with phase-in, as initial results suggest there is a problem with how the phase-in was implemented for this type of policy.

Figure 9: Change in Unemployment Rates, Pre-Announcements, Power Sector Performance Standard

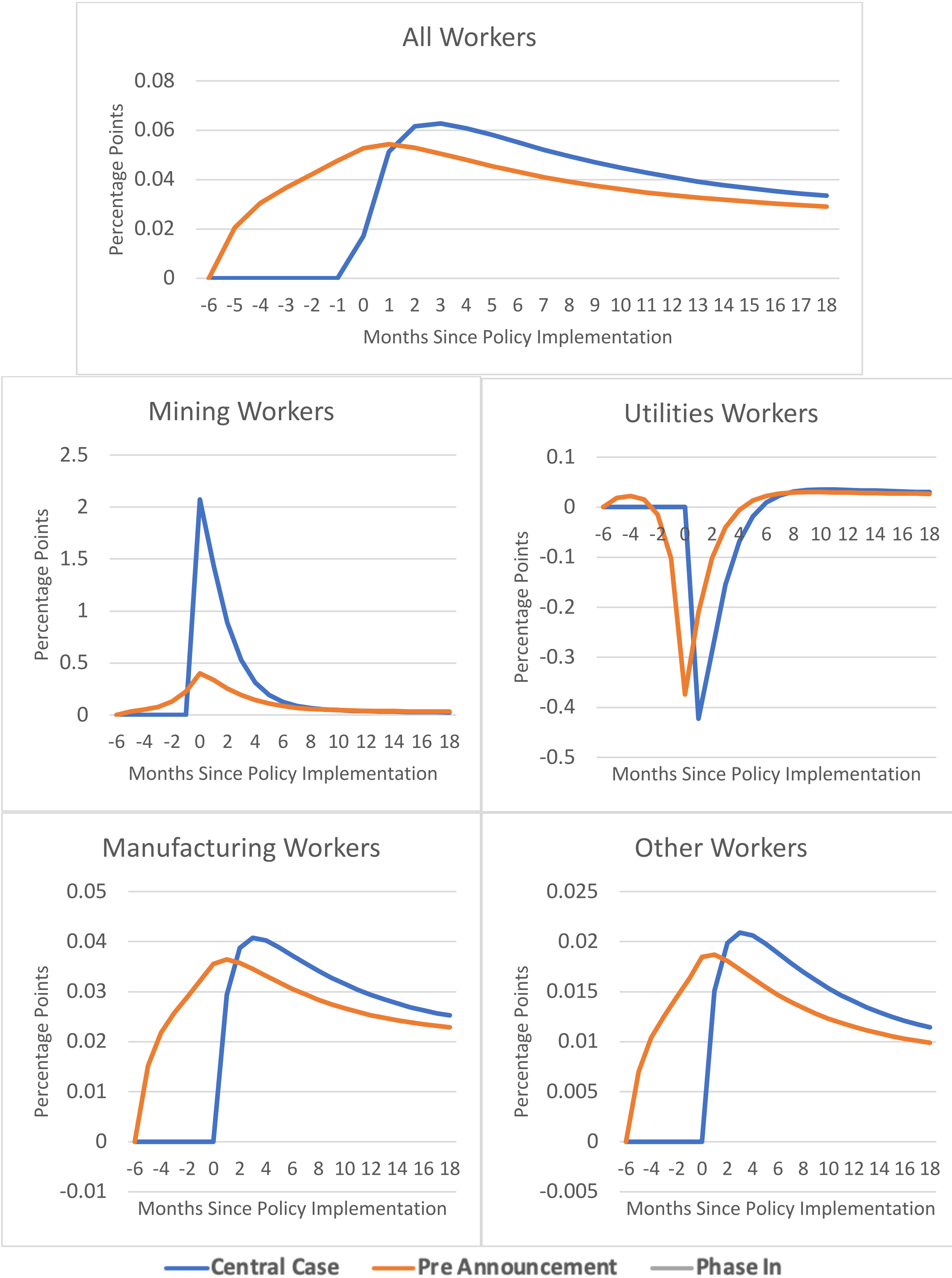


Figure 10: Change in Unemployment Rates, Pre-Announcements and Phase-Ins, Power Sector Carbon Tax

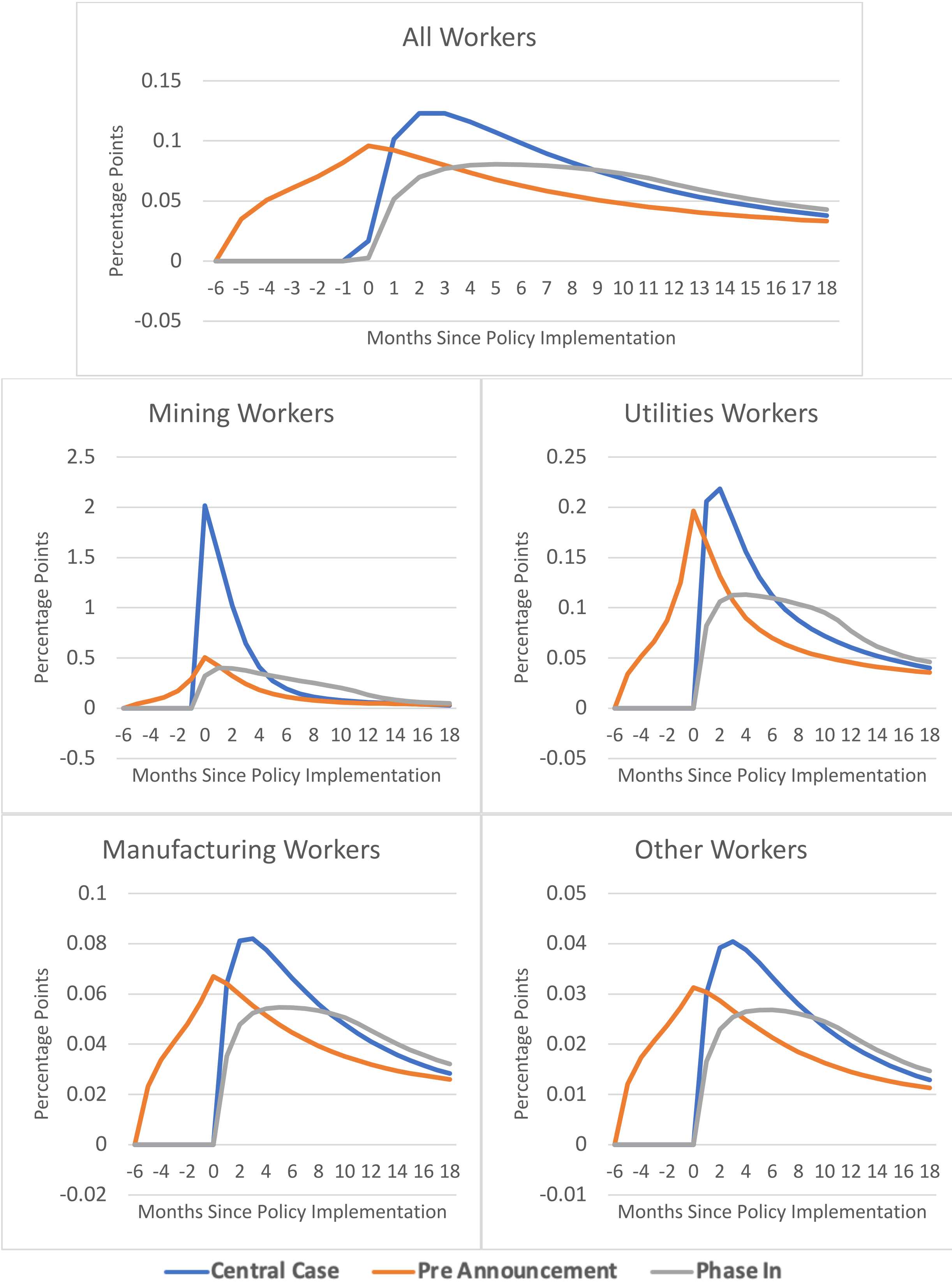
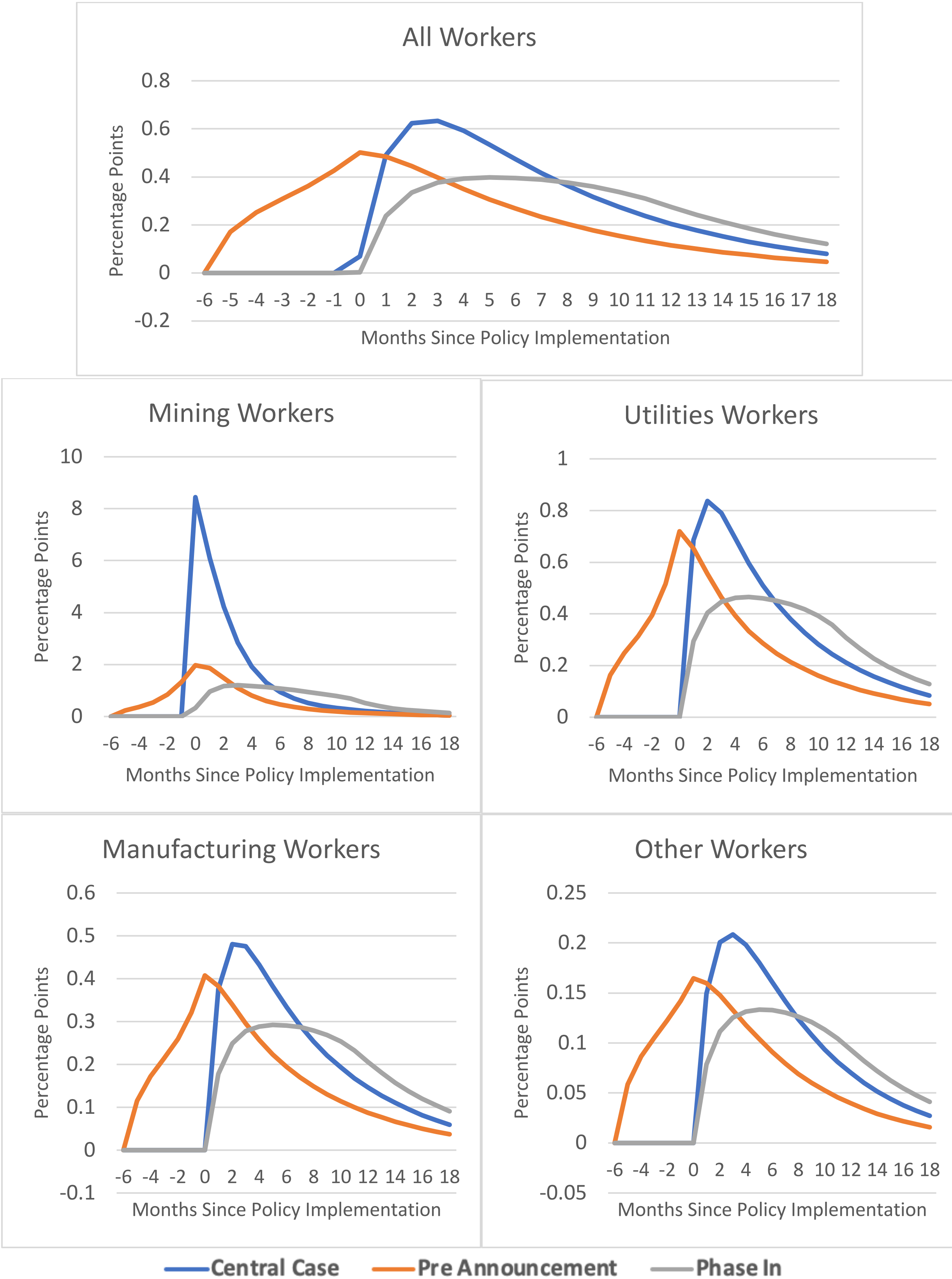


Figure 11: Change in Unemployment Rates, Pre-Announcements and Phase-Ins, Economy-Wide Carbon Tax



These results suggest that pre-announcements and/or phase-ins can substantially mitigate short-run labor market disruption (and the accompanying distributional effects). While phase-ins and pre-announcements still likely have efficiency costs (see Williams, 2012), one can easily imagine that the value of avoiding substantial short-run increases in unemployment (both in the aggregate and for particular worker groups) could outweigh that efficiency cost.

Moreover, these represent relatively brief phase-ins and preannouncements. Proposals often phase in new policies over a period of substantially more than a year, and preannounce by much more than six months. Lengthening the phase-in or preannouncement period would presumably limit the short-run increases in unemployment to an even greater extent.

5. Conclusions

This paper extends previous work to create a multi-sector general-equilibrium model that incorporates key labor market features (especially labor-market search frictions) that limit workers' movement to new jobs and new industries: slowed cross-industry matching and sticky wages. It then uses that model to examine how the labor-market effects of policy vary across workers initially employed in different industries, focusing on three policies aimed to reduce energy-related carbon dioxide emissions in the US: a power sector performance standard, power sector carbon tax, and an economy-wide carbon tax.

Our analysis shows that the effects of these policies on unemployment rates, earnings, and length of unemployment spells differ substantially across worker groups. Unsurprisingly, workers initially employed in fossil-fuel and energy-intensive industries face much more negative effects than workers initially employed in other industries. These effects vary substantially depending on the ease with which workers can switch industries and on how quickly wages can adjust. But the basic pattern of results is robust across a wide range of parameter values.

We also show that phase-ins or preannouncement of policy – even by a relatively brief period – can substantially mitigate the short-run increase in unemployment and loss of earnings at the start of these policies, both at the aggregate level and for workers in industries most heavily affected.

One key caveat is that this relatively simple model only captures some of the factors that limit workers' movement across industries in response to policy. Workers differ only in what industry they're currently employed in (or last worked in); beyond that, there is no skill heterogeneity, job- or occupation-specific human capital, or similar factors. As a result, we are likely underestimating the divergence in effects across workers.

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