DECARBONIZATION IN AN INTERDEPENDENT WORLD WITH NOMINAL WAGE RIGIDITIES*

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Abstract

Although climate change is one of the most pressing global challenges, there has been a backlash against reducing carbon emissions, regarding potential negative economic impacts. In this paper, we analyze how decarbonization policies affect short-run unemployment through the lens of a quantitative general equilibrium trade and environment model that incorporates downward nominal wage rigidities. Our findings indicate that uniformly increasing emission reduction targets can indeed lead to a rise in unemployment. However, we also observe that the unemployment effects are very heterogeneous across countries by their emission intensity; more emission-intensive countries tend to experience higher and more prolonged transitionary unemployment. This spatial heterogeneity across sectors and countries underscores the potential for coordinated international environmental policies to mitigate unemployment effects and facilitate the transition to more resilient, greener economies.

JEL Classification Codes: F16, F42, F64, J64

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1 Introduction

Climate change is one of the pressing issues in the 21st century. Even though the anthropogenic climate change is already happening in our lifetime, people, including many policymakers, seem to resist reducing carbon emissions. Besides political reasons, are there also innate, economic consequences of reducing carbon emissions? We know that in the long-run, a greener economy is a desirable outcome, but there may be economic consequences in sectors or industries that emit carbon emissions relatively more. When the United States withdrew from the Paris Agreement, President Donald Trump stated,

> The Paris Climate Accord is simply the latest example of Washington entering into an agreement that disadvantages the United States to the exclusive benefit of other countries, leaving American workers — who I love — and taxpayers to absorb the cost in terms of lost jobs, lower wages, shuttered factories, and vastly diminished economic production. (Trump, June 2017)

Similar claims have been made that environmental policies may potentially lead to loss of many jobs. However, we still do not know whether, and to what extent these potential economic consequences are true. Therefore, to achieve more resilient greener economy, we need to have better understanding of the short-run economic consequences of environmental policies.

In this paper, we investigate how environmental policies through the reduction of carbon emissions affect short-run unemployment through the lens of a quantitative New Keynesian trade model. A country that emits more greenhouse gases (GHG) with higher intensity will be more affected by environmental policies. Furthermore, through international trade, there will be potential spillovers to other countries as countries have GHG emission reduction targets. Therefore, to fully understand how climate policy in one country affects another country, we need to carefully model trade flows.

To investigate how environmental policies affect unemployment, we develop a quantitative multi-country, multi-sector international trade model with downward nominal rigidities, following Rodríguez-Clare et al. (2022). Our model takes a gravity model structure in trade and dynamic discrete industry choice, following Caliendo et al. (2019), and also includes the downward nominal wage rigidities similar to Schmitt-Grohé and Uribe (2016). In this framework, we add the environmental context in terms of carbon emissions from production similar to Larch and Wanner (2017, 2024).

In our economy, each sector in each country specializes in producing a particular good, which are traded and aggregated across countries à la Armington. Firms are competitive and have constant-returns-to-scale technology, using emissions and labor as their factor inputs. On the household side,

agents choose their consumption, which sector to work in, and how much of labor that they would like to provide in the sector of their choosing. Household agents are forward looking and they have perfect foresight into the future. When agents choose which sector to work in, they also face two types of frictions: (i) migration costs between sectors within a country, and (ii) idiosyncratic shocks similar to Artuç et al. (2010).

One of the most important mechanisms is that each sector's production uses energy emissions as inputs. If there are no binding emission targets, then energy prices are given as an exogenous global energy price, which leads to each country having a perfectly elastic supply of energy. However, when the emissions targets are binding, the amount of energy is exogenously given, and prices are determined endogenously. Then, there will be country-specific energy prices for countries that have binding emission targets. If emission targets bind, it leads to an increase in the prices of goods in that sector. As the sectoral prices increase, the relative demand for production declines, leading to a decrease in nominal wages in the sectors with binding emission targets. Due to downward nominal rigidities, if nominal wages decline significantly, there will be unemployment in the short run.

In our model, there are two key differences across countries that make international trade to be important in understanding how one country's environmental policy can potentially spillover to another. First, countries have different comparative advantages across industries. Furthermore, within a particular country, industries have heterogeneous energy shares in their production. When a country with relatively higher energy shares implements climate policy, their relative demand declines as prices increase. If nominal wage rigidities bind, then there will be unemployment. Since there is trade, export declines as relative prices become more expensive. Then, demand for foreign goods increases as consumers substitute for cheaper imports, which causes domestic unemployment to increase further. Therefore, international trade plays an important role in amplifying domestic environmental policies.

We then use our model to quantify the effects of environmental policies through more stringent emission targets on short-run unemployment by calculating changes to labor market reallocations over time. We use bilateral trade, expenditure on intermediates, and final consumption expenditures from the World Input-Output Table (WIOT), labor market data from the Social Economic Account (SEA), and the total CO_2 emission for each sector in each country from the Environmental Account (EA). Using these data, we match various endogenous moments in our model.

We quantify our model using 42 countries and with the rest of the world (ROW) and use 18 sectors, using the sectors defined from Caliendo and Parro (2015). With our quantified, general equilibrium model, we ask the following preliminary simulation question: if all countries have to decrease their

emission targets by 90% in one period, how would the short-run unemployment dynamics and the distribution of workers across sectors change?[1] In our simulation, we start at a baseline steady-state equilibrium and reduce CO_2 by 90% for all countries so that emission targets are met in $t = 1$.

First, we find that countries that have a relatively higher portion of emission-intensive sectors will experience higher unemployment compared to countries with lower shares of low-emission-intensive sectors. Our analysis finds that many Eastern European economies, led by Russia, will suffer higher short-run unemployment. However, the effects on developed economies are not as high. On a sector level, energy and chemical sectors have relatively higher unemployment compared to other sectors. This is intuitive as these two sectors are relatively more emission-intensive.

Second, we find that there is an interesting pattern of unemployment dynamics, where unemployment decreases gradually over time. The highest unemployment rate in each country is reached by the first period and starts decreasing gradually until it reaches full employment. The degree of how fast unemployment dissipates depends on each country's economic reliance on emission-intensive sectors. If a country relies more on emission-intensive sectors, a decline in unemployment seems to be more gradual. This short-run unemployment dynamics is mainly driven by the interaction between nominal wage adjustment over time; the more emission-intensive sectors are, the harder the nominal wages will bind.[2]

Our paper contributes to the following three strands of literature. First, our paper relates to the growing work on the development of quantitative environmental and energy models in open economy settings; e.g., Babiker (2005), Elliott et al. (2010), Egger and Nigai (2015), Böhringer et al. (2016), Shapiro (2016), Larch and Wanner (2017, 2024), and Farrokhi (2020). All of these papers study the global implications of environmental policies, but they do not focus on the labor market dynamics. We introduce downward nominal wage rigidities (DNWR) in our quantitative trade and environment model to understand the trade-induced trade-off between decarbonization and short-run unemployment.

Second, our paper also relates to the literature on the impact of trade on unemployment. Many papers study the distributional effects of trade on inequality; e.g. Davidson and Matusz (2006), Dutt et al. (2009), Adão et al. (2022), and Galle et al. (2023). There is a strand of literature that studies the effects of trade on unemployment through labor search frictions, such as Helpman et al. (2010), Heid and Larch (2016), Kim and Vogel (2020, 2021), and Dix-Carneiro et al. (2023). Perhaps the closest

[1] This is an extremely stringent policy we are considering. However, as our first preliminary simulation, we believe it is necessary to include such extreme cases to understand how our model behaves better.

[2] For the current set of quantitative analyses, we do not have migration costs between sectors. We plan to include migration costs, and we expect that this would prolong the unemployment adjustment process.

paper to ours is Rodríguez-Clare et al. (2022), where they introduce DNWR in a quantitative trade model to study the effects of trade on short-run unemployment. We add the new environmental channel through the reduction of emission targets in a quantitative trade model with DNWR to link the impact of environmental policies on unemployment to better understand how trade linkages are used as potential policy spillover channels.

Lastly, we also contribute to the rich literature on New Keynesian open-economy models with downward nominal wage rigidities. Following the work on Clarida et al. (2002), Gali and Monacelli (2005), Gali and Monacelli (2008), Galí and Monacelli (2016), Nakamura and Steinsson (2014), Schmitt-Grohé and Uribe (2016), and Chodorow-Reich and Wieland (2017), we introduce DNWR to a quantitative trade and environment model to better understand how in the presence of DNWR, how environmental policies can potentially cause unemployment effects in a short-run, and how trade can cause country-specific environmental policies to spill over to other countries.

The paper is organized as follows. In Section 2, we document heterogeneous cost shares of emissions across industries and countries. In Section 3, we introduce the quantitative model of trade and environment with downward nominal wage rigidities. In Section 4, we discuss how we solve the model using the hat-algebra methodology. In Section 5, we discuss various data that we used for our quantification, along with the initial parameters. In Section 6, we use our model to run a simulation exercise to show the short-run unemployment effects of environmental policies. In Section 7, we conclude the paper.

2 Empirical Facts

Immediate and deeper carbon emissions reductions will raise production costs, particularly for industries and countries with higher cost shares of energy/carbon emissions.[3] In this section, we document which industries are most likely to face the largest cost increases under tighter emissions targets and which countries may encounter the greatest challenges. Specifically, we highlight three empirical facts: 1) cost shares of emissions vary significantly across sectors and across countries within industries, 2) cost shares of emissions for a given industry generally decline as countries develop, and 3) the relationship between average cost shares of emissions and country development follows an inverted U-shape. The analysis in this section is based on data from the Global Trade Analysis Project (GTAP, see Aguiar et al., 2022).

[3] As for our quantification, we will assume that emissions are directly proportional to energy use, we use the notions of energy cost shares and emission cost shares interchangeably.

Fact 1: Heterogeneous Cost Shares of Emissions by Sector and Country

Figure 1 shows a box plot illustrating the median and variation of cost shares of emissions across countries by industry. The variation across industries is significant, with Chemicals being the most carbon-intensive industry, with a median of 4.5%, and non-tradables being the least intensive, with a median of 0.6%. Importantly, the within-industry variation is even more pronounced. For Chemicals, the cost share of emissions for countries at the 75th percentile is 9.7%, while at the 25th percentile, it is 1.9%. This 1.9% value is almost comparable to the 1.6% cost share at the 75th percentile for Agriculture, which is one of the least emission-intensive industries in terms of the median. These findings suggest that both industrial composition and differences in the cost structure within industries across countries are important for evaluating the decarbonization effects on employment demand.

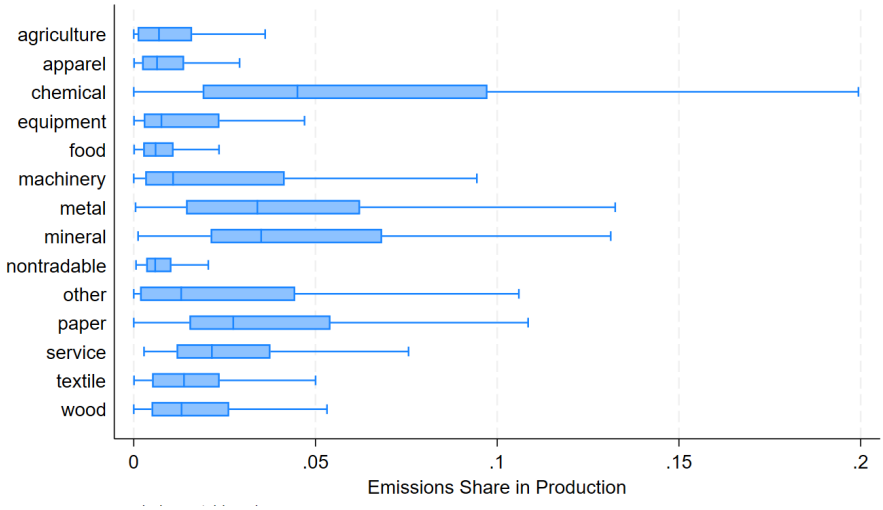


Figure 1: Cost Shares of Carbon Emissions by Sectors

Fact 2: Lower Cost Share of Emissions with Development within an Industry

A natural question following Fact 1 is what explains the within-industry variation in the cost shares of emissions across countries. Figure 2 shows the estimated coefficient of the cost share of emissions on the logarithm of GDP per capita, which serves as an approximation of a country's development level. With the exception of Agriculture and Food, we find that the estimated coefficients are negative, indicating that more developed countries tend to adopt cleaner production technologies and have lower cost shares of carbon emissions.

Fact 3: Inverted U-shape Relationship between Cost Share of Carbon Emissions and Development

Differences in industrial composition and the varying cost structure within industries across coun-

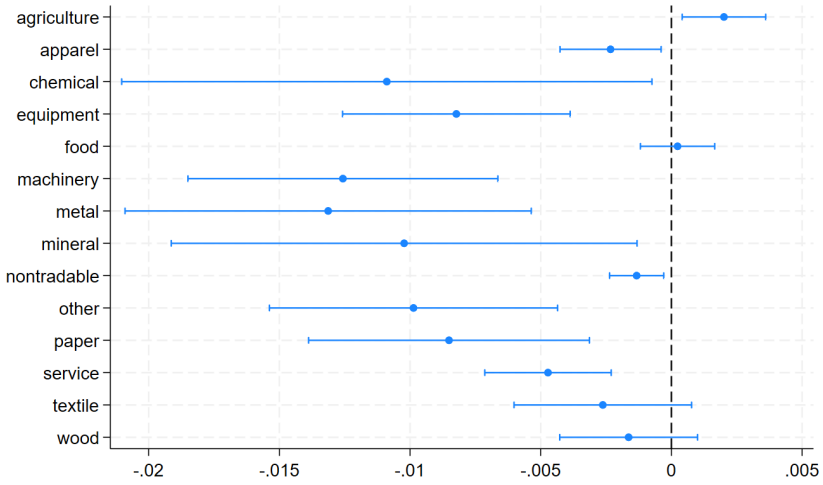


Figure 2: Estimated Relationship between GDP per capita and Cost Share of Carbon Emissions by Industry

tries shape the variation in average cost shares of carbon emissions. Figure 3 shows a bin scatter plot illustrating the relationship between a country's development and its average cost share of emissions, weighted by industry sales. The relationship mirrors the environmental Kuznets curve: initially, a country's production is less emission-intensive, but as industrial composition changes, emissions intensity increases. The shift to cleaner technologies eventually dominates, leading to a decline in the country's average cost share of emissions.

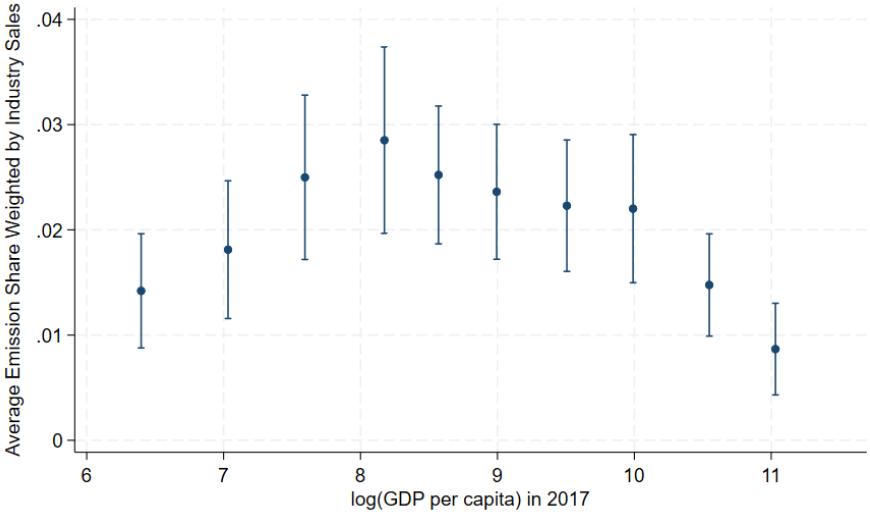


Figure 3: Country Average Cost Share of Emissions and Development

These empirical findings highlight the potential challenges of international cooperation on carbon emissions reduction. Countries differ in both the composition of industries and the cost shares within industries. As a result, the same change in the price of carbon emissions may have varying effects

on labor demand across countries as production demand shifts from more carbon-intensive countries to less carbon-intensive ones. In the following section, we develop a model that incorporates these empirical observations to quantitatively evaluate the employment effects of decarbonization.

3 A Quantitative Model of Trade and Downward Nominal Wage Rigidities

In this paper, we develop a multi-country, multi-sector quantitative environmental trade model with labor dynamics to examine the short-run unemployment effects of environmental policies across countries. We combine the quantitative trade and environmental framework of Larch and Wanner (2017) and Larch and Wanner (2024) with labor dynamics incorporating downward nominal wage rigidities (DNWR) from Rodríguez-Clare et al. (2022). The model includes N countries, indexed by $i, n \in N$, and J sectors, indexed by j. Each country produces a sectoral intermediate good by combining labor and emissions as inputs, and these intermediates are aggregated using a standard Armington setup with iceberg trade costs to produce sectoral output. We model carbon emissions reduction policies as binding emissions targets, where tighter constraints limit the availability of emissions as an input, raising emissions prices and production costs. If one country experiences a greater cost increase than another, production and labor demand shift accordingly. These shifts in labor demand may lead to short-run unemployment if wage adjustments are insufficient, as modeled through DNWR. Additionally, workers face mobility costs when transitioning across sectors, further hindering the reallocation of labor from more adversely affected industries to those less affected.

3.1 Production

Final Goods Production

The final output in country n is denoted by

$$y_{n,t} = \prod_{j=1}^{J} \left(y_{n,t}^{j} \right)^{\gamma_n^j}, \tag{1}$$

where $y_{n,t}^{j}$ is the Armington aggregated goods in sector j, with γ_n^j as the Cobb-Douglas share, with $\sum_{j \in J} \gamma_n^j = 1$. This final goods production technology delivers us the following final goods price

index

$$P_{n,t} = \prod_{j=1}^{J} \left(P_{n,t}^{j} \right)^{\gamma_n^j}, \tag{2}$$

which we interpret as the consumer price index (CPI) of country n, where $P_{n,t}^{j}$ is the output price for sector j in country n.

Intermediate Goods Production

In each sector $j \in J$ in country n, there is a representative intermediate good-producing firm that produces using the following Cobb-Douglas technology:

$$q_{n,t}^{j} = A_{n,t}^{j} \left(E_{n,t}^{j} \right)^{\alpha_n^j} \left(L_{n,t}^{j} \right)^{1-\alpha_n^j}, \tag{3}$$

where $q_{n,t}^{j}$ is the intermediate output in sector j in country n at time t, and $E_{n,t}^{j}$ and $L_{n,t}^{j}$ are the amount of emissions and employed workers as factor inputs, respectively. The Cobb-Douglas share, α_n^j, is the cost share of emissions in the production of the intermediate output.[4]

Countries can trade their intermediate goods in each sector j. Traded goods are subject to bilateral iceberg cost, where a particular sector's intermediate good in sector j shipped from country i to country n requires producing $d_{ni,t}^{j} \geq 1$ amount of units. We assume that trading within a country is costless (If $n = i$, $d_{ii,t}^{j} = 1$). The cost minimization problem of the representative producer yields the bilateral import price for country n of goods produced by country i in sector j as:

$$p_{ni,t}^{j} = d_{ni,t}^{j} \frac{(e_{i,t})^{\alpha_i^j} \left(W_{i,t}^{j} \right)^{1-\alpha_i^j}}{A_{i,t}^{j}}, \tag{4}$$

where $e_{i,t}$ is the emission price in country i, $W_{i,t}^{j}$ is the wage rate for employed workers in industry j in country i, and $A_{i,t}^{j}$ denotes total factor productivity.

The crucial modeling choice in our paper is that environmental policy operates through emission prices. Our model considers two environmental policy scenarios: (i) countries with binding emission targets and (ii) countries without binding emission targets.

First, suppose country n has binding emission targets. Given the equilibrium expenditure on sector j intermediate goods produced in country n, $Y_{n,t}^{j}$, the emissions price for country n is defined

[4]One way of rationalizing emissions as an input with corresponding cost share α is to assume that they are a side output, but can be partly be abated as in Copeland and Taylor (2003) Alternatively, one can think of α as an energy/fossil fuel cost share and emissions being proportional to this input.

as:

$$e_{n,t} = \frac{\sum_{j \in J} \alpha_n^j Y_{n,t}^j}{\bar{E}_{n,t}}, \tag{5}$$

where $\bar{E}_{n,t}$ represents the binding emission target for country n to achieve by period t at the national level. Given the aggregate demand for carbon emissions in production, this equation shows that a more ambitious emission target increases the sectoral emissions price, $e_{n,t}$.

Now, suppose country n does not have binding emission targets. In this case, we assume that there is a global emissions price, $\bar{e}_t$, that is exogenously determined and associated with a perfectly elastic endogenous emissions supply. Without binding emission targets:

$$e_{n,t} = \bar{e}_t. \tag{6}$$

International Trade The intermediate goods are aggregated by a CES technology by sector with elasticity of substitution σ^j. Given the Armington assumption, we can derive the bilateral imports share from origin i in destination n:

$$\pi_{ni,t}^j = \frac{\left(p_{ni,t}^j\right)^{1-\sigma^j}}{\sum_{i'=1}^N \left(p_{ni',t}^j\right)^{1-\sigma^j}}, \tag{7}$$

and the sectoral price index:

$$P_{n,t}^j = \left[\sum_{i=1}^N \left(p_{ni,t}^j\right)^{1-\sigma^j}\right]^{\frac{1}{1-\sigma^j}}. \tag{8}$$

Total production sales of intermediate good production for sector j in country i is

$$Y_{i,t}^j = \sum_{n=1}^N \pi_{ni,t}^j X_{n,t}^j = \sum_{n=1}^N \pi_{ni,t}^j \gamma_n^j \left(\sum_{j \in J} \left(W_{n,t}^j L_{n,t}^j\right) + e_{n,t} E_{n,t}\right) \tag{9}$$

where $X_{n,t}^j$ is the total expenditure, γ_n^j is the expenditure share on industry j in country n, and $E_{n,t} = \sum_j E_{n,t}^j$ is the aggregate demand for carbon emissions in country n. Recall that carbon emissions policy affects emission prices and, consequently, the prices of goods. These price changes can lead to unemployment effects from decarbonization through international trade: as relative prices shift due to policy changes, trade shares adjust, causing shifts in production demand that may significantly reduce labor demand in some countries.

3.2 Labor Dynamics

We model two layers of labor dynamics, following Rodríguez-Clare et al. (2022). First, the labor market in each sector and country is constrained by downward nominal wage rigidities, which limit the ability of wages to adjust downward. This constraint may force the market to ration employment below the available labor supply if labor demand is insufficient, resulting in short-run unemployment. This unemployment persists until wage adjustments are complete or labor redistributes across industries. The second layer involves mobility frictions, which workers face when transitioning between industries. These frictions hinder workers from promptly adjusting to changes in market conditions across industries, prolonging the unemployment effects compared to a frictionless scenario.

Downward Nominal Wage Rigidities

Specifically, a country faces the following constraint on downward nominal wage adjustments at the industry level:

$$W_{n,t}^{j} \geq \delta_n W_{n,t-1}^{j}, \quad \delta_n \geq 0. \tag{10}$$

For example, if $\delta_n = 0.98$, as used in our quantitative analysis, the market cannot reduce wages by more than 2% within a single period.

Let $L_{n,t}^{j}$ denote the number of workers employed, and $\ell_{n,t}^{j}$ denote the number of workers seeking employment opportunities in industry j in country n. With potential unemployment in the economy:

$$L_{n,t}^{j} \leq \ell_{n,t}^{j}. \tag{11}$$

When labor demand in the market declines sufficiently and wage adjustments hit the lower bound, employment $L_{n,t}^{j}$ may fall below the number of workers available in the market, $\ell_{n,t}^{j}$, resulting in unemployment.

Either equation (10) or (11) is always satisfied. Specifically, the following complementary slackness condition holds in each industry and country labor market:

$$(L_{n,t}^{j} - \ell_{n,t}^{j}) \times (W_{n,t}^{j} - \delta_n W_{n,t-1}^{j}) = 0. \tag{12}$$

Importantly, nominal downward wage rigidities would not pose a problem if countries could generate sufficient inflation through monetary policy. Following Rodríguez-Clare et al. (2022), we assume that such monetary policy is constrained globally by the following nominal anchor condition.[5]

$$\sum_{n}^{N}\sum_{j}^{J}\frac{W_{n,t}^{j}L_{n,t}^{j}}{1-\alpha_{n}^{j}}=\gamma\sum_{n}^{N}\sum_{j}^{J}\frac{W_{n,t-1}^{j}L_{n,t-1}^{j}}{1-\alpha_{n}^{j}}. \tag{13}$$

Worker Mobility Frictions across Industries

In each period, workers solve a dynamic discrete choice problem to determine which industry market to enter in the following period, with the objective of maximizing their lifetime value function. Workers are forward-looking, with perfect foresight regarding macroeconomic equilibrium conditions. However, they experience idiosyncratic taste shocks across industries in each period, resulting in heterogeneous market choices among workers from the same origin.

The lifetime value function of worker in country n and industry j at period t is:

$$v_{n,t}^{j}=\ln\omega_{n,t}^{j}+\eta_{n,t}^{j}+\max_{k\in J}\left\{\beta E[v_{n,t+1}^{k}]-\tau_{n,t}^{jk}+\nu\varepsilon_{n,t}^{jk}\right\}, \tag{14}$$

where $\omega_{n,t}^{j}$ represents the expected real wage from working in industry j, $\eta_{n,t}^{j}$ denotes non-wage benefits from working in the industry (e.g., amenities), and $\tau_{n,t}^{jk}$ is the utility cost incurred by workers when moving from industry j to k. The term $\varepsilon_{n,t}^{jk}$ captures idiosyncratic taste shocks, with ν scaling the influence of these shocks on industry choice relative to the expected market value.

We assume that workers in the same industry, whether employed or unemployed, collectively hedge unemployment risk within the market. As a result, each worker receives an employment rate-adjusted expected wage, which they spend on final goods:

$$\omega_{n,t}^{j}=\frac{L_{n,t}^{j}}{\ell_{n,t}^{j}}\frac{W_{n,t}^{j}}{P_{n,t}^{j}}. \tag{15}$$

This assumption significantly simplifies the data requirements for our quantitative analysis while still enabling us to evaluate the unemployment effects arising from the imbalance between excess labor supply and insufficient demand in the market following the implementation of environmental policy.

Assuming that idiosyncratic taste shocks are drawn from a Type-I extreme value distribution, the

[5]This constraint reflects the notion that central banks are reluctant to permit excessively high inflation (see Woodford, 2003; Guerrieri et al., 2021). For a more detailed discussion of this condition, see Rodríguez-Clare et al. (2022).

expected value function for industry j in country n is given by:

$$V_{n,t}^{j} = \ln \omega_{n,t}^{j} + \eta_{n,t}^{j} + \ln \left(\sum_{k=0}^{K} \exp \left(\beta V_{n,t+1}^{k} - \tau_{n,t}^{jk} \right)^{1/\nu} \right)^{\nu} \tag{16}$$

and the share of workers in industry j at period t who move to industry k in the following period is:

$$\mu_{n,t}^{jk} = \frac{\exp \left(\beta V_{n,t+1}^{k} - \tau_{n,t+1}^{j,k} \right)^{1/\nu}}{\sum_{k' \in K} \exp \left(\beta V_{n,t+1}^{k'} - \tau_{n,t+1}^{j,k'} \right)^{1/\nu}}. \tag{17}$$

The share of workers transitioning from industry j to k, combined with the distribution of workers in period t, determines the law of motion for worker distribution in the subsequent period:

$$\ell_{n,t+1}^{k} = \sum_{j \in K} \mu_{n,t}^{jk} \times \ell_{n,t}^{j}. \tag{18}$$

As a remark, this equation describes the distribution of workers, including both employed and unemployed individuals. Employment within each industry is constrained by downward nominal wage rigidities. If labor demand in an industry is insufficient and wage adjustments are limited by these rigidities, the employment rate, $L_{n,t}^{j}/\ell_{n,t}^{j}$, may fall below one.

3.3 Labor Demand Implications of Emissions Targets

To illustrate how carbon emissions reduction policies can shift production demand across countries, potentially leading to unemployment effects, this subsection explores the partial equilibrium implications of tighter binding targets on production demand shifts. Specifically, we consider two cases with all the countries set emissions binding targets: (1) countries coordinating to set the same emissions reduction rate and (2) countries setting different emissions reduction rates. Our discussion here is limited to a partial equilibrium perspective, focusing on the immediate impact of emissions price changes on trade share adjustments and the resulting production demand shifts, while holding all other factors constant.

Suppose countries coordinate to set the same emissions reduction rate, $1/\kappa_t < 1$. From equation (5), the immediate impact of this policy on the emission price, assuming production demand remains constant, is an increase in the emission price by a factor of $\kappa_t > 1$. Note that relative trade share

depends on relative price, and thus relative emission price

$$\frac{\pi^j_{ni,t}}{\pi^j_{ni',t}} = \left(\frac{(e_{i,t})^{\alpha^j_i}}{(e_{i',t})^{\alpha^j_{i'}}}\right)^{1-\sigma^j} \left(\frac{d^j_{ni,t}}{d^j_{ni',t}} \frac{A^j_{i',t}}{A^j_{i,t}} \frac{(W_{i,t})^{1-\alpha^j_i}}{(W_{i',t})^{1-\alpha^j_{i'}}}\right)^{1-\sigma^j}. \tag{19}$$

The immediate impact of a tighter emissions target on relative trade shares operates through the first term on the right-hand side of the equation above, specifically via changes in relative production costs driven by the emissions price. While the emissions price increases at the same rate, its impact may differ across countries due to varying elasticities, expressed as $(\kappa_t)^{-(\sigma^j-1)(\alpha^j_i-\alpha^j_{i'})}$. These elasticities are influenced by differences in the cost share of emissions in production across countries and are further amplified by the trade elasticity.

Implication 1. *When countries coordinate to set the same emissions reduction rate, there is no shift in production or labor demand across countries if $\alpha^j_i = \alpha^j_n$ for all $n \neq i$ and for every industry j. However, if $\alpha^j_i \neq \alpha^j_n$ for some $n \neq i$ and industry j, the coordinated reduction rate will lead to shifts in production and labor demand across countries, potentially resulting in short-run unemployment effects.*

This straightforward implication of our model highlights the challenges of international cooperation in reducing carbon emissions. While a coordinated policy may appear fair across countries, it could disproportionately impact certain markets, potentially inducing unemployment effects if labor demand shifts are substantial.

What if countries set different emissions reduction rates? Suppose countries design emissions reduction rates to avoid trade share adjustments in a specific industry j. Such reduction rates, $1/\kappa_{n,t}$, must satisfy $\kappa_{i,t} = (\kappa_{n,t})^{\alpha^j_n/\alpha^j_i}$ for the targeted industry j. In other words, countries could potentially set emissions reduction rates that account for differences in the cost shares of emissions across countries. However, this policy would be effective only for the targeted industry. For other industries $k \neq j$, labor demand shifts would still occur if $\alpha^j_n/\alpha^j_i \neq \alpha^k_n/\alpha^k_i$.

Implication 2. *When countries coordinate to set different emissions reduction rates that account for differences in the cost share of emissions across countries, they can achieve no shift in production or labor demand across countries while reducing global emissions, provided that $\alpha^j_i/\alpha^j_n = \alpha^k_i/\alpha^k_n$ for all $n \neq i$ and $j \neq k$. However, if $\alpha^j_i/\alpha^j_n \neq \alpha^k_i/\alpha^k_n$ for any $n \neq i$ or $k \neq j$, these coordinated reduction rates at the national level will lead to shifts in production and labor demand across countries in certain industries, potentially resulting in short-run unemployment effects.*

As discussed in Section 2, there are substantial variations in the cost shares of emissions across industries and within industries across countries. The heterogeneous relationships between cost shares

and development levels by industry further suggest significant variability in relative cost shares across industries. These straightforward implications of our model, combined with the observed data patterns, underscore the challenges of coordinating global emissions reduction efforts. However, the extent to which these challenges pose practical concerns is a quantitative question. Using our model, we quantitatively assess the potential unemployment effects of decarbonization and explore more effective coordination strategies to achieve the global goal of immediate and deep emissions reductions while minimizing unemployment effects.

4 Solving the Model

4.1 Model Equilibrium in Relative Change

To avoid the need for estimating and calibrating all economic parameters and fundamentals within the model, we follow the exact-hat algebra methodology proposed by Dekle et al. (2007). Let $\hat{x}_t = x_t/x_0$ represent the ratio between the counterfactual period-t economy (x_t) and the baseline economy (x_0) for any given variable or parameter. In this context, $\hat{x}_t$ corresponds to one plus the percentage change of a variable as it transitions from the baseline scenario to the counterfactual economy. Using this notation, we can reformulate all equilibrium conditions in terms of exact-hat algebra.

The hat-form expressions for unit cost, price index, and bilateral trade shares can be rewritten as follows:

$$\hat{c}_i^j = [\hat{W}_{i,t}^j]^{1-\alpha_i^j}[\hat{e}_{i,t}]^{-\alpha_i^j} \tag{20}$$

$$\hat{\pi}_{ni,t}^j = \frac{\left[\frac{\hat{d}_{ni,t}^j \hat{c}_{i,t}^j}{\hat{A}_{i,t}^j}\right]^{1-\sigma^j}}{\sum_{m=1}^N \pi_{nm,0}^j \left[\frac{\hat{d}_{nm,t}^j \hat{c}_{m,t}^j}{\hat{A}_{m,t}^j}\right]^{1-\sigma^j}} \tag{21}$$

$$\hat{P}_{n,t}^j = \left(\sum_{m=1}^N \pi_{nm,0}^j \left[\frac{\hat{d}_{nm,t}^j \hat{c}_{m,t}^j}{\hat{A}_{m,t}^j}\right]^{1-\sigma^j}\right)^{\frac{1}{1-\sigma^j}} \tag{22}$$

The market clearing conditions for both goods and factors can be rewritten as follows:

$$Y_{i,t} = \left[\sum_{j=1}^{J}(W_{i,0}^{j}L_{i,0}^{j}) \times (\hat{W}_{i,t}^{j}\hat{L}_{i,t}^{j})\right] + (e_{i,0}E_{i,0}) \times (\hat{e}_{i,t}\hat{E}_{i,t}) \tag{23}$$

$$X_{i,t}^{j} = \gamma_{i}^{j}Y_{i,t} \tag{24}$$

$$\hat{W}_{i,t}^{j}\hat{L}_{i,t}^{j} \times (W_{i,0}^{j}L_{i,0}^{j}) = (1-\alpha_{i}^{j})\sum_{n=1}^{N}\pi_{ni,0}^{j}\hat{\pi}_{ni,t}^{j}X_{n,t}^{j} \tag{25}$$

$$\hat{e}_{i,t}\hat{E}_{i,t} \times (e_{i,0}E_{i,0}) = \sum_{j=1}^{J}\alpha_{i}^{j}\sum_{n=1}^{N}\pi_{ni,0}^{j}\hat{\pi}_{ni,t}^{j}X_{n,t}^{j} \tag{26}$$

The relative change in nominal wage is also subject to nominal wage rigidity. Therefore, the complementarity slackness condition can be represented as follows:

$$\left(1 - \frac{\hat{L}_{i,t}^{j}L_{i,0}^{j}}{\hat{\ell}_{i,t}^{j}\ell_{i,0}^{j}}\right)(\hat{W}_{i,t}^{j} - \delta_{i}^{j}\hat{W}_{i,t-1}^{j}) = 0 \tag{27}$$

When conducting counterfactual analyses, we slightly modify our original labor market dynamic settings. In the initial framework, each worker incurs a mobility cost when moving out of the sector they were previously employed in. This original specification includes an equilibrium condition that provides a full matrix of labor flows from one sector to another across all countries. However, applying this specification in hat-algebra for counterfactuals would require baseline data on bidirectional labor flows for all countries, which is not available.

To address this data limitation, we simplify our model by assuming that workers choose their sector of employment at the end of each period without incurring migration costs. In this revised specification, each sector in each country offers workers a specific amenity value, denoted by η_{i}^{j}. Consequently, our modified framework can match the labor distribution across sectors, though it lacks the richer dynamics of bidirectional labor flows across sectors found in the original model. The derivation and detailed specification of this simplified approach are presented in the appendix. The

Parameter	Value	Meaning	Source
α_n^j	-	energy shares	WIOT & SEA
γ_n^j	-	final consumption exp. shares	WIOT
σ^j	-	trade elasticity	Caliendo and Parro (2015)
ν	0.6	migration elasticity	Caliendo et al. (2019)
β	0.9	discount factor	common value
δ_n^j	0.98	wage rigidity	Rodríguez-Clare et al. (2022)
Moments	**Value**	**Meaning**	**Source**
$\pi_{ni,0}^j$	-	imported trade shares	WIOT
$\ell_{n,0}$	-	total employment	SEA
$L_{n,0}^j/\ell_{n,0}^j$	1	employment rate	full employment at initial steady state
$E_{n,0}$	-	total CO_2 emission	EA
$W_{n,0}^j$	-	wages	SEA
$e_{n,0}$	-	energy prices	SEA and EA
$\mu_{n,0}^j$	-	employment distribution	SEA

Table 1: Parameter values and initial moments.

equilibrium conditions in terms of relative changes are listed below.

$$\hat{\omega}_{i,t}^j = \frac{\hat{L}_{i,t}^j}{\hat{\ell}_{i,t}^j} \times \frac{\hat{W}_{i,t}^j}{\hat{P}_{i,t}} \tag{28}$$

$$\hat{\mu}_{i,t+1}^j = \frac{[\hat{u}_{i,t+1}^j]^{\beta/\nu}[\hat{\tilde{\eta}}_{i,t+1}^j]^{1/\nu}}{\sum_{k=1}^J \mu_{i,0}^k[\hat{u}_{i,t+1}^k]^{\beta/\nu}[\hat{\tilde{\eta}}_{i,t+1}^k]^{1/\nu}} \tag{29}$$

$$\hat{u}_{i,t}^j = \hat{\omega}_{i,t}^j[\hat{\eta}_{i,t+1}^j]^{-\nu}[\hat{u}_{i,t+1}^j]^{\beta}\hat{\tilde{\eta}}_{i,t+1}^j \tag{30}$$

$$\hat{\ell}_{i,t}^j = \hat{\mu}_{i,t}^j \times \hat{\ell}_{i,t} \tag{31}$$

With all equilibrium conditions expressed in terms of relative changes, we can now define a dynamic equilibrium. Given an initial steady-state equilibrium, and a path of shocks and emission targets, $\{\hat{\tilde{\eta}}_{i,t}^j, \hat{d}_{ni,t}^j, \hat{A}_{i,t}^j, \hat{E}_{i,t}\}$, that converges to constants, an equilibrium is a path of labor wages $\hat{W}_{i,t}^j$, labor distribution $\hat{\mu}_{i,t}^j$, energy prices $\hat{e}_{i,t}^j$, and employment rates $\hat{L}_{i,t}^j/\hat{\ell}_{i,t}^j$ (all in terms of relative change) that satisfy all equilibrium conditions and also converge to constants.

5 Quantification

This paper's counterfactual analysis relies on several endogenous variables, which include bilateral trade shares denoted by π_{ni}^{j}, total labor compensation $W_i^j L_i^j$, and total energy expenditure $e_i E_i$. Additionally, shares that reflect economic structures, such as labor shares and energy shares α_i^j, play a crucial role in shaping the model. The common parameter values are drawn from established literature sources. Specifically, the trade elasticity for each industry j is based on estimates from Caliendo and Parro (2015), while the labor migration elasticity ν is set to 0.6, as per Caliendo et al. (2019). To account for price rigidity, we follow Rodríguez-Clare et al. (2022) and set the DNWR parameter δ_i^j to 0.98. Lastly, the discount factor is chosen as $\beta = 0.9$, in line with common macroeconomic parameters. A detailed summary of these parameters and their respective sources is provided in Table 1.

For our benchmark economy, we utilize the 2016 release of the World Input-Output Database (WIOD) developed by Timmer et al. (2015). This database traces the flow of goods and services across countries at the industry level for the period 2001–2014. We designate 2014 as the base year for our analysis, aligning our model variables with the actual values observed in that year. Our quantitative model includes 42 countries, with an additional "rest of the world" (ROW) category, and encompasses 18 sectors, aggregated from an original set of 56 industries. Refer to Tables 3 and 2 in the Appendix for details on industry aggregation and the list of included countries.

The World Input-Output Table (WIOT) in the WIOD database provides harmonized input-output matrices that track both international and domestic transaction flows across sectors. We utilize these matrices to compute bilateral trade shares, $\pi_{i,n}^{j}$, final consumption shares, γ_i^j, and total expenditure on energy for each sector.

The WIOD's Socio-Economic Accounts (SEA) offer industry-level data, including total labor compensation, number of persons employed, and value-added output. We use this information to directly impose the initial distribution of labor across sectors, $\mu_{i,0}^{j}$, and labor compensation at the country-sector level, $W_{i,0}^j L_{i,0}^j$. We retrieve total energy expenditure and total value added at the country-sector level. The ratio of total energy expenditure to value-added output is then taken as the energy share α_i^j, while the remainder, $1 - \alpha_i^j$, is attributed to labor.

For emissions data, we refer to the Environmental Accounts (EA) compiled by Corsatea et al. (2019) for the Joint Research Centre of the European Commission. This dataset provides detailed information on energy consumption and CO_2 emissions by industry and country, aligned with the 2016 release of the World Input-Output Database (WIOD). Using these data, we aggregate sectoral CO_2 emissions across sectors within each country and use this sum as the initial CO_2 emissions level,

denoted as $E_{n,0}$.

To provide an overview of the emission shares obtained from the WIOD, we summarize the relative emissions generated by different countries. Figure 4a illustrates the average emission shares across various countries, where these shares are calculated by averaging emissions across sectors, weighted by the value-added output in each sector. This approach gives a more accurate representation of emissions by considering the economic contributions of each sector within a country.

Notably, countries such as Bulgaria, China, and Russia exhibit the largest emission shares. This is largely due to their reliance on energy-intensive industries and higher shares of fossil fuel consumption relative to other countries. In the case of China, rapid industrialization and reliance on coal-fired power have significantly contributed to its high emissions. Similarly, Russia's large-scale energy production, particularly in oil and gas, along with Bulgaria's dependence on coal,[6] underpins their substantial emission shares. These countries' sectoral structures and energy dependencies thus play a crucial role in their emission profiles, highlighting the influence of both economic composition and energy sources on overall national emissions.

Figure 4b presents the emission shares distributed across sectors, calculated by averaging across countries with weights based on each sector's value-added output. This approach allows us to understand the relative contributions of different sectors to global emissions in proportion to their economic significance.

The figure reveals that the energy and transportation sectors hold the largest shares of emissions. This result is expected, as both sectors are inherently energy-intensive and heavily reliant on fossil fuels. The energy sector, which includes electricity generation, oil extraction, and gas production, is a primary source of greenhouse gases due to its substantial use of coal, oil, and natural gas in generating power for industrial, commercial, and residential use. Similarly, the transportation sector contributes significantly to emissions through the widespread use of gasoline and diesel in road transport, aviation, and shipping.

Figure 4c displays the complete matrix of emission shares across various sectors and countries, offering a comprehensive overview of how emissions are distributed globally. This detailed visualization reinforces the patterns previously observed: certain countries consistently exhibit higher emission intensities across multiple sectors, and specific sectors remain emission-intensive regardless of the country.

The persistence of these results highlights underlying structural and economic factors. Countries with higher emission intensities often have economies that are heavily reliant on fossil fuels, less

[6] See Agence France-Presse (2024) for a discussion.

efficient technologies, or energy-intensive industries such as heavy manufacturing and mining. For example, nations with abundant natural resources like coal or oil may have sectors that contribute disproportionately to emissions due to extraction and processing activities.

Similarly, sectors such as energy production and transportation consistently show higher emission shares across different countries. This is attributed to their inherent reliance on fossil fuels and the current global dependency on carbon-intensive energy sources for electricity generation and mobility. The energy sector, in particular, is a significant contributor due to the combustion of coal, oil, and natural gas for power generation. The transportation sector adds to this through emissions from vehicles, aircraft, and ships, which predominantly use petroleum-based fuels.

The complete matrix in Figure 4c allows for a granular observation of emission patterns, facilitating the identification of key areas where emission reduction efforts could be most impacted.

6 Results

In this section, we quantify both the cross-sectional and dynamic effects of stringent environmental policies on short-run employment across different sectors and countries. Our quantitative exercise is a forward-looking one, to answer the what-if scenarios of different environmental policies.

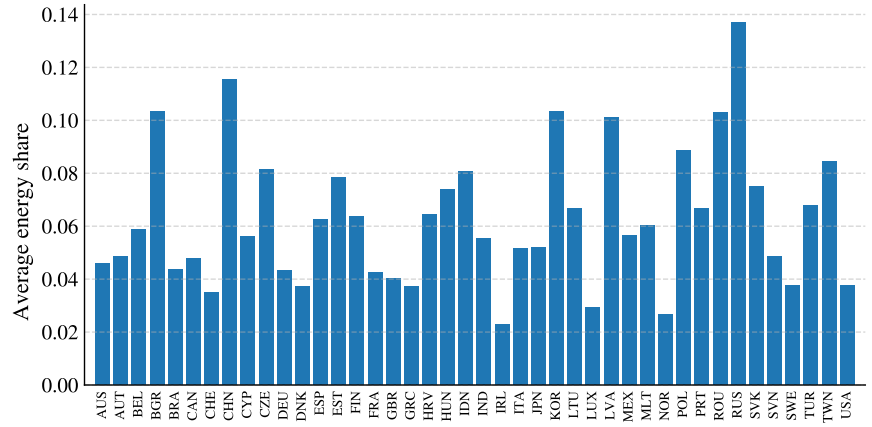
In our quantification, we assume that the global economy starts at a baseline steady-state equilibrium at $t = 0$. We run a simulation where each country has to reduce their CO_2 levels by 90%, and they are forced to meet their emission reduction targets in the next period ($t = 1$).[7] We document our preliminary results below.

Cross-Sectional Unemployment Rates in $t = 1$

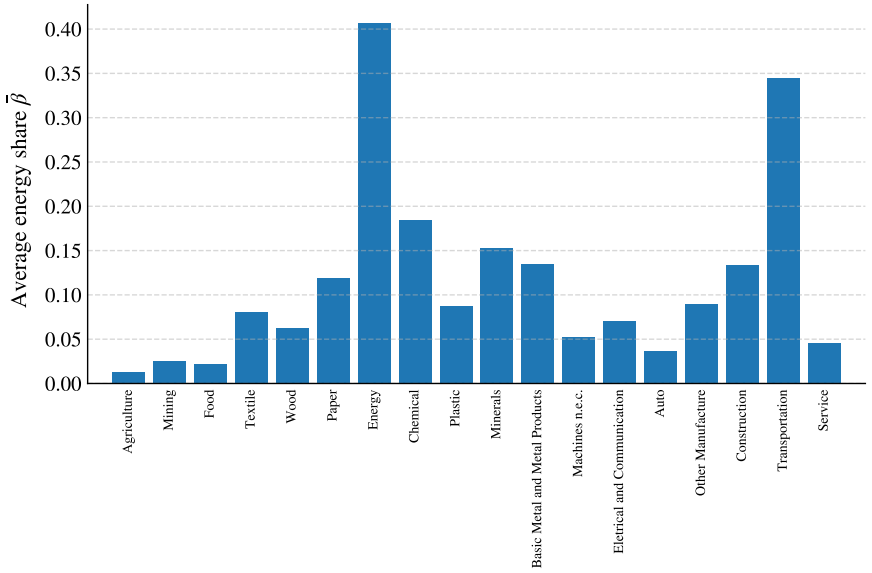
We present our results first by looking at the cross-sectional distribution of unemployment across countries in our quantification. Figure 4(a) presents the unemployment rates at $t = 1$ by countries. The figure shows that when there is an increase in emission target reduction, almost all of the countries experience unemployment increase. However, we also observe heterogeneity among different countries. Russia is affected by the most, followed by Bulgaria and Romania. When we consider the U.S., the unemployment rate increase is around 0.5%, which is not as large as one may have anticipated.[8] Also, we know that the U.S. is relatively a closed economy, which mitigates the spillover of other countries' energy policies.

[7] We are currently running additional simulation exercises.

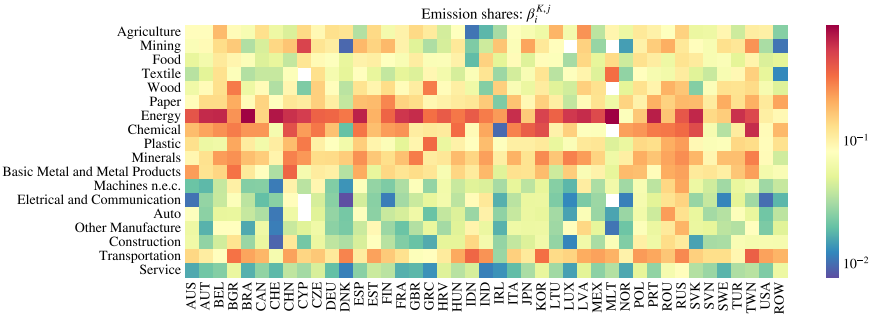
[8] However, we do have to keep in mind that this unemployment rate increase is purely coming from the environmental policy effects. Depending on how you look at it, this number also could be a significant increase.



(a) Avg. Emission Shares by Country



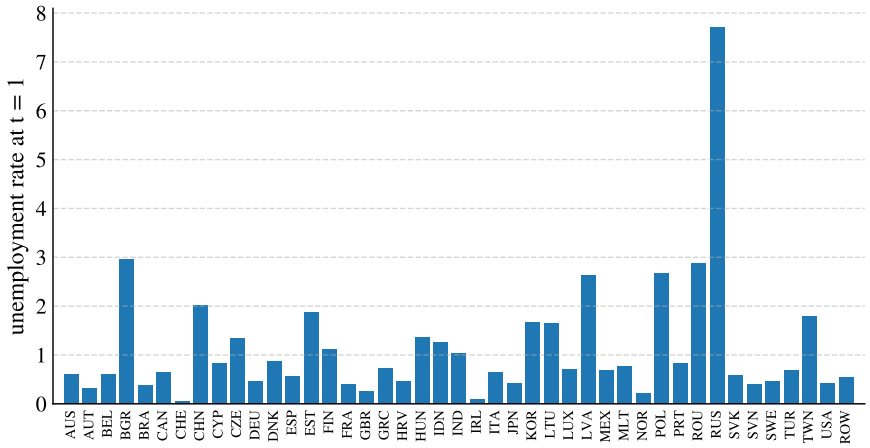
(b) Avg. Emission Shares by Sector



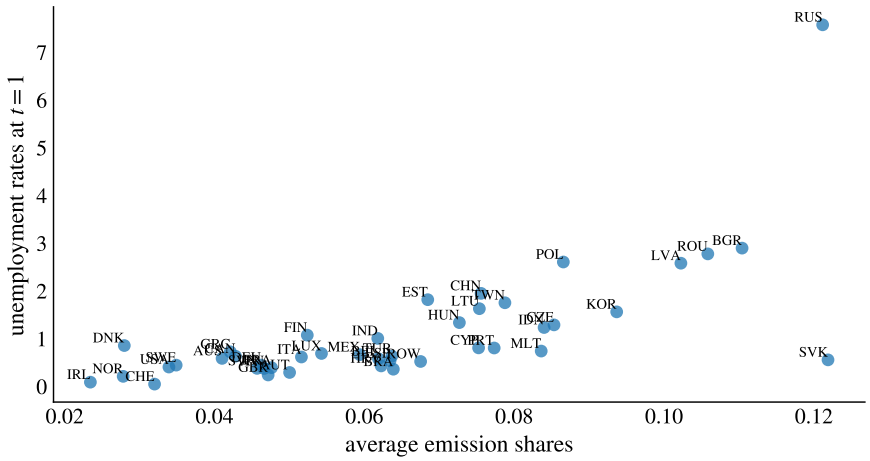
(c) Emission Shares by Country and Sector

Figure 4: Emission Shares from Data.

What is a driving force behind the heterogeneity across unemployment rates across different countries? When we look at Figure 4(b), we find that the degree of emission share in sectoral productions plays a critical role in determining the heterogeneity. The increase in unemployment rate is positively correlated with the emission share in their production. The higher presence of emission-intensive sectors, the higher unemployment the country will experience.



(a) By Country



(b) vs Emission Share

Figure 5: By Country Unemployment Rates after the Decarbonization Policy ($t = 1$)

Our quantitative analysis also helps us to decompose what is happening within countries, across sectors as well. Figure 5 gives us the unemployment rate after the decarbonization policy in $t = 1$ by sector and by country. The heat map tells us that the higher the shades are, unemployment rate is higher in that sector in that country. Two interesting patterns arise.

First, there is also sectoral heterogeneity in the increase in unemployment rate. The most of the increase in unemployment across countries are primarily driven by the following sectors: energy,

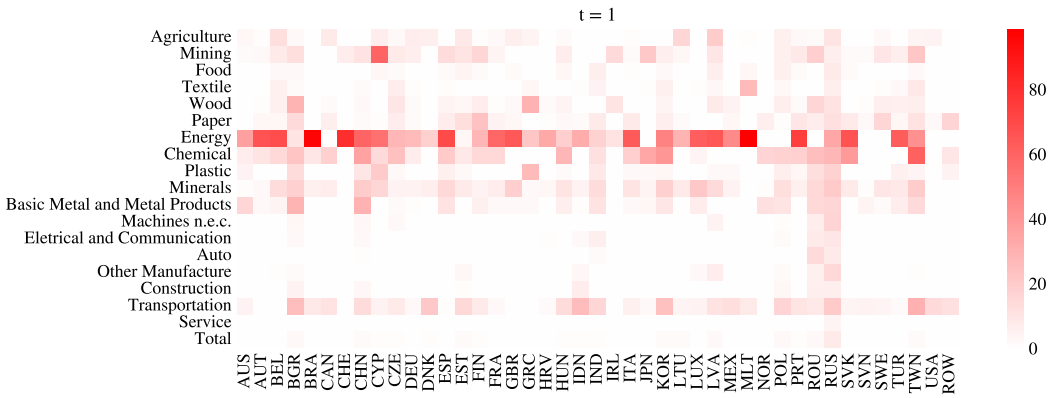


Figure 6: By Sector-Country Unemployment Rates after the Decarbonization Policy ($t = 1$)

chemical, and minerals. These three sectors tend to be energy-emission intensive compared to the other sectors. The service sector tends to be not emission-intensive, and we see that we barely observe any increase in unemployment rate. Second, we also observe that there is more interesting heterogeneity across countries as well. If we observe Russia, we see that the majority of the sectors are experiencing unemployment compared to other countries. This is because the sectoral emission shares vary across countries. Russia tend to have higher emission shares across their sectors, which cause their relative prices to be higher than the other economies, which put higher downward wage pressure on their sectors compared to the sectors in other countries.

By looking at the above figures and that there are heterogeneous spatial distributions of the aggregate unemployment rates across the global economy tell us that there is room for potential coordination across countries, in terms of emission target reductions, to mitigate negative effects on labor market.

Unemployment Rate Dynamics

Figure 6 plots unemployment rate dynamics across time, starting from the initial steady-state. We plot two countries that have the highest unemployment rate in $t = 1$ (Russia and Bulgaria), U.S., and China. From Figure 6, we find that unemployment rate reaches its peak at $t = 1$, and gradually decline. U.S. reaches back to full employment after about 10 periods. However, if the country's first period unemployment rate was higher, than it takes longer to go back to full employment. For Russia and Bulgaria, it takes almost 30 periods for short-run unemployment to disappear.

The mechanism that plays very crucial role in gradual adjustment of unemployment rate dynamics is the downward nominal wage rigidities. As more stringent emission target reduction forces sectoral prices to go up, wages for workers decrease. However, since the wages are binding by the

wage rigidity parameter every period, it takes longer for countries to get rid of the short-run unemployment rate, especially for those who have higher presence of emission-intensive sectors.

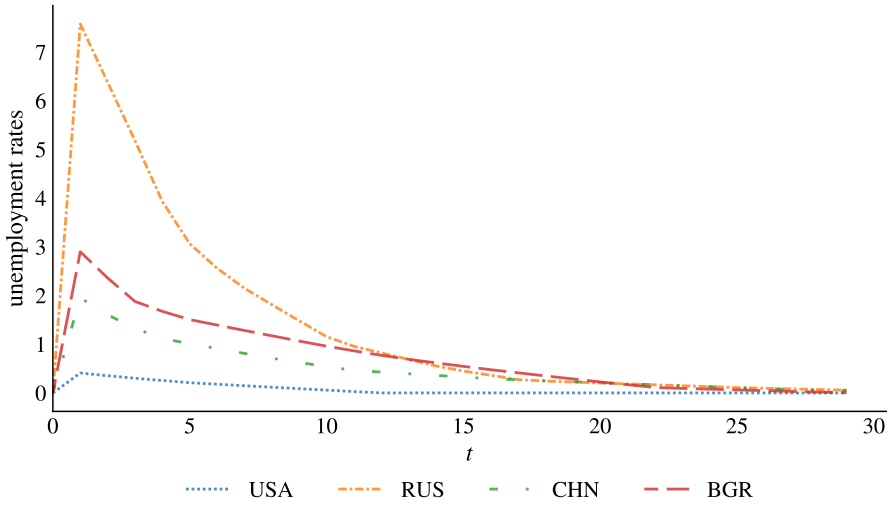


Figure 7: Unemployment Dynamics

7 Conclusion

Whether environmental policies have macroeconomic consequences has been one of the most important questions to both researchers and policymakers. In this paper, we develop a quantitative model of trade and environment to understand how stricter environmental policies through higher emission targets affect short-run unemployment in different countries. There are two important channels that we build in our model: (i) international trade linkages and (ii) downward nominal wage rigidities. When there is international trade, as countries simultaneously reduce their emissions by the same rate, we see the relative prices for more emission-intensive countries go up more than non-emission-intensive countries. Then, for emission-intensive countries' nominal wages fall more, which leads to higher short-run unemployment with the presence of downward nominal wage rigidities.

In our quantified model, we confirm that there is indeed short-run unemployment, and the effects are heterogeneous across countries. Unemployment is gradually adjusted across different countries, and it takes some time to return to full employment. Countries that are more emission-intensive tend to suffer from higher unemployment.

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APPENDIX

A Derivations

In this section, we present a simplified version of the labor dynamics module. In our initial framework, each worker incurs a mobility cost when transitioning from one sector to another. However, to streamline our model, we assume that workers select their sector of employment at the end of each period without facing migration costs. Each sector within a country offers workers a specific amenity value, denoted by η_i^j, which represents the non-wage benefits associated with employment in that sector.

The lifetime value function for a worker in country n and industry j at period t is formulated as follows:

$$v_{n,t}^j = \ln \omega_{n,t}^j + \eta_{n,t}^j + \max_{k \in J} \left\{ \beta E[v_{n,t+1}^k] + \nu \varepsilon_{n,t}^{jk} \right\}, \tag{32}$$

where $\omega_{n,t}^j$ indicates the expected real wage from working in industry j, and $\eta_{n,t}^j$ represents the amenities or non-wage benefits associated with employment in the sector. The function captures workers' preferences for current period benefits and potential future benefits across different sectors, integrating expectations about future values and idiosyncratic factors affecting sector transitions.

The model incorporates idiosyncratic taste shocks, which are drawn from a Type-I extreme value distribution. Given this structure, the expected value function for a worker in industry j in country n at period t can be expressed as:

$$V_{n,t}^j = \ln \omega_{n,t}^j + \eta_{n,t}^j + \ln \left(\sum_{k=0}^{K} \exp \left(\beta V_{n,t+1}^k \right)^{1/\nu} \right)^{\nu}, \tag{33}$$

where $\omega_{n,t}^j$ represents the expected real wage, $\eta_{n,t}^j$ is the non-wage amenity in sector j, and β captures the discount factor over time. The summation term reflects the expected future utilities across all potential industries k, weighted by each industry's respective utility component.

The model further allows us to determine the share of workers in industry j at period t, represented by $\mu_{n,t}^j$, as follows:

$$\mu_{n,t}^{j} = \frac{\exp\left(\beta V_{n,t+1}^{j} + \eta_{n,t+1}^{j}\right)^{1/\nu}}{\sum_{k\in K}\exp\left(\beta V_{n,t+1}^{k} + \eta_{n,t+1}^{k}\right)^{1/\nu}}. \tag{34}$$

This expression reflects the probability that a worker chooses industry j based on the relative utilities across industries, where ν captures the elasticity of substitution in workers' choices. The share $\mu_{n,t}^{jk}$ thus represents how workers distribute themselves across sectors in response to the expected utility differentials, balancing both wage and amenity factors.

We introduce two transformations to simplify the notation: let $\tilde{\eta}_{i,t}^{j} = \exp(\eta_{i,t}^{j})$, which denotes the exponential of the amenity value, and $u_{i,t}^{j} = \exp(V_{i,t}^{j})$, representing the exponential of the expected value function. Under these transformations, the equilibrium conditions for the worker distribution and sector utility can be expressed as follows:

$$\mu_{i,t+1}^{j} = \frac{\left[u_{i,t+1}^{j}\right]^{\beta/\nu}\left[\tilde{\eta}_{i,t+1}^{j}\right]^{1/\nu}}{\sum_{k=1}^{J}\left[u_{i,t+1}^{k}\right]^{\beta/\nu}\left[\tilde{\eta}_{i,t+1}^{k}\right]^{1/\nu}}, \tag{35}$$

where $\mu_{i,t+1}^{j}$ is the share of workers in industry j in country i at period $t+1$, and

$$\left[u_{i,t}^{j}\right]^{1/\nu} = \left(\omega_{i,t}^{j}\right)^{1/\nu} \times \left(\sum_{k=1}^{J}\left[u_{i,t+1}^{k}\right]^{\beta/\nu}\left[\tilde{\eta}_{i,t}^{k}\right]^{1/\nu}\right). \tag{36}$$

These conditions define the equilibrium distribution of workers across sectors as a function of both wage and amenity values, adjusted by the elasticity of substitution parameter ν.

Furthermore, these equilibrium conditions can now be trivially reformulated using a hat-algebra approach to express percentage changes in terms of proportional growth, facilitating comparative statics and dynamic analysis within the model framework.

B Addtional Tables

Table 2: List of WIOD countries.

ISO-3 Code	Country Name	ISO-3 Code	Country Name	ISO-3 Code	Country Name
AUS	Australia	FIN	Finland	LVA	Latvia
AUT	Austria	FRA	France	MEX	Mexico
BEL	Belgium	GBR	United Kingdom	MLT	Malta
BGR	Bulgaria	GRC	Greece	NOR	Norway
BRA	Brazil	HRV	Croatia	POL	Poland
CAN	Canada	HUN	Hungary	PRT	Portugal
CHE	Switzerland	IDN	Indonesia	ROU	Romania
CHN	China	IND	India	RUS	Russia
CYP	Cyprus	IRL	Ireland	SVK	Slovakia
CZE	Czech Republic	ITA	Italy	SVN	Slovenia
DEU	Germany	JPN	Japan	SWE	Sweden
DNK	Denmark	KOR	Republic of Korea	TUR	Turkey
ESP	Spain	LTU	Lithuania	TWN	Taiwan
EST	Estonia	LUX	Luxembourg	USA	United States

Table 3: Concordance of WIOD sectors.

WIOD description	WIOD Code	Industry	WIOD description	WIOD Code	Industry
Crop and animal production	A01	Agriculture	Land transport	H49	Transportation
Forestry and logging	A02	Agriculture	Water transport	H50	Transportation
Fishing and aquaculture	A03	Agriculture	Air transport	H51	Transportation
Mining and quarrying	B	Mining	Warehousing	H52	Transportation
Food products, beverages and tobacco products	C10-C12	Food	Postal activities	H53	Transportation
Textiles, wearing apparel and leather products	C13-C15	Textile	Accommodation and food	I	Service
Wood and cork	C16	Wood	Publishing	J58	Service
Paper	C17	Paper and Printing	Media	J59_J60	Service
Printing and reproduction of recorded media	C18	Paper and Printing	Telecommunications	J61	Service
Coke and refined petroleum products	C19	Energy	Computer and information	J62_J63	Service
Chemical products	C20	Chemical	Financial services	K64	Service
Pharmaceutical products	C21	Chemical	Insurance	K65	Service
Rubber and plastic products	C22	Plastic	Auxiliary to financial services	K66	Service
Other non-metallic mineral products	C23	Minerals	Real estate	L68	Service
Basic metals	C24	Basic Metal and Metal Products	Legal and accounting	M69_M70	Service
Fabricated metal products	C25	Basic Metal and Metal Products	Architectural	M71	Service
Electronic and optical products	C26	Electrical and Communication	Scientific research	M72	Service
Electrical equipment	C27	Electrical and Communication	Advertising	M73	Service
Machinery and equipment	C28	Machines n.e.c.	Other professional	M74_M75	Service
Motor vehicles	C29	Auto	Administrative	N	Service
Other transport equipment	C30	Auto	Public administration	O84	Service
Furniture	C31_C32	Other Manufacture	Education	P85	Service
Repair and installation of machinery	C33	Other Manufacture	Human health and social work	Q	Service
Electricity and gas	D35	Energy	Other service	R_S	Service
Water supply	E36	Service	Activities of households as employers; undifferentiated goods- and services-producing activities of hosueholds for own use	T	Service
Sewerage and waste	E37-E39	Service			
Construction	F	Construction			
Wholesale and retail vehicles	G45	Service	Activities of extraterritorial organizations and bodies	U	Service
Wholesale trade	G46	Service			
Retail trade	G47	Service			