Online Appendix for: Domestic Politics in the European Union's Emissions Trading System: Evidence from Free Allowance Allocation

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Formal Model

The strategic interaction features a politician, a set of J firms indexed by j, and a continuum of individuals of mass 1 indexed by i. Individuals are located in D districts indexed by d. The size of each district is β_d, where $\beta_d < \frac{1}{2}$ for all d. In broad strokes, firms produce a good that creates emissions that a politician seeks to regulate by setting a cap. Individuals have preferences over consumption of the good but also incur disutility from pollution damages, and must decide whether or not to vote for the politician.

Firms engage in production of a good x_j sold at market price p. I assume that firms are price takers, i.e., the market is competitive. I make this restriction because inter-firm strategic interactions are not of direct relevance or interest to the political problem that will be outlined below (i.e., I do not focus on the prices of produced goods in the empirical analysis). Market demand is $p = P(X)$, where $X = \sum_j x_j$ is total output. Firms have production costs $c_j(x_j)$. Production of x_j leads to emissions $e_j = \delta_j x_j$. Let $E = \sum_j e_j$. The parameter δ_j determines how "dirty" firm j's production process is. I will assume that $c_j(x_j) = c(x_j) = \frac{1}{2}x_j^2$ and that $\delta_j = \delta$ for all j, so firms are symmetric both in their costs of production as well as their mapping from production to emissions. Symmetry is used to facilitate presentation of results but is not necessary.

The politician sets a cap on emissions $L \in [0, \hat{L}]$ which places a limit on the maximum amount of emissions. Furthermore, firms receive initial allowances $\bar{e}_j$ for free, which effectively subsidize emissions. If a firm wants to emit more than $\bar{e}_j$, it must purchase allowances at a price σ, which in reduced-form captures the price of allowances on the secondary market (i.e., traded between firms). The system of free allowance allocation in the European Union required commitment on behalf of policymakers to abstract away from strategic behavior among economic agents within the permit market (Metcalf 2009; Verde et al. 2019). Profits for firm j are thus

$$\pi_j(x_j, e_j) = px_j - c(x_j) - \sigma(e_j - \bar{e}_j).$$

As firms produce, individuals within the polity consume. Let individuals have the following utility function:

$$U_{id}(x) = u(x) + z - D_d(E) + \varepsilon_{id},$$

where $u(x) = \log(x)$ is utility from consuming the good produced by firms, z is income spent on other goods, and $D_d(E) = \frac{1}{2}E^2$ is the damage function from emissions in district d. The damage function captures the disutility that individuals incur from firms' negative externalities involved in production (i.e., emissions). That damage is homogeneous across districts is a simplifying assumption to ease presentation of the model but not necessary for the results. Finally, $\varepsilon_{id} \sim U[-\frac{1}{2\omega_d}, \frac{1}{2\omega_d}]$ is an individual-specific valence shock drawn from a district-specific distribution. Notice that within districts, individuals are identical in their preferences over consumption, but receive idiosyncratic shocks to their utility. These represent other electorally salient issues other than consumption of the good x and the pollution it creates. Based on their utility consumption and damage, individuals decide whether to vote for the politician or not as in a simple probabilistic voting model (Lindbeck and Weibull 1987).

Finally, given firms' profits and individuals' expected vote decisions, the politician chooses the cap L to maximize a convex combination of social welfare (as determined by the economic model) and political support (as determined by the probabilistic voting model that derives from the economic model). Let $W(L)$ be social welfare and $\Lambda(L)$ be the politician's expected vote share, both to be derived. Thus, the politician's utility can be expressed as

$$V(L) = \alpha\Psi\Lambda(L) + (1-\alpha)W(L) + \sum_j \nu_j b_j(\bar{e}_j).$$

The parameter $\alpha \in [0,1]$ modulates the politician's relative preference for maximizing social welfare versus maximizing votes. The case of $\alpha = 1$ is a politician purely interested in reelection; the case of $\alpha = 0$ is a politician functioning like a utilitarian social planner. The parameter $\Psi > 0$ represents the benefits of holding office. Finally, for technical reasons, suppose that the politician receives an infinitesimal benefit $b_j(\bar{e}_j)$ from providing free allowances to firm j; I assume the functions $b_j(\cdot)$ are increasing and strictly concave, but take all $\nu_j \to 0$ in the analyses. These additively separable benefits allow for the characterization of each firm's endowment rather than simply solving for the aggregate cap L. Substantively, one could interpret these terms as the politician's idiosyncratic affinities for each firm.

I make one assumption about the size of the cap relative to other parameters, which is that there is relative scarcity between the maximum cap and the number of firms in the economy. In reality, EU leaders were guided by documents like the Kyoto Protocol burden-sharing agreement and could not design an infinitely large cap.

Assumption 1 $\hat{L} < a\delta J - 1$.

The timing of the model is:

1. The politician commits to an allocation plan $(\bar{e}_1, \dots, \bar{e}_J)$ which creates a cap L.
2. Firms receive their free allowances and produce $(x_1, \dots, x_J)$ generating emissions $(e_1, \dots, e_J)$.
3. Individuals make consumption decisions and vote for the politician or not.

I solve for the subgame perfect equilibrium of the game via backward induction. I first derive the equilibrium of economic actors and then use that to find the politician's optimal cap.

Economic Equilibrium

I characterize the economic behavior of firms in the production and permit markets. Recall that firms maximize profit

$$\pi_j(x_j, e_j) = px_j - c(x_j) - \sigma(e_j - \bar{e}_j).$$

Firms choose output x_j taking as given the market price p and the price of permits σ. Maximizing profits yields the first-order condition

$$p - c'(x_j) - \sigma\delta = 0,$$

which yields optimal output

$$x_j(p; \sigma) = p - \sigma\delta.$$

I now derive the equilibrium price of goods p and the equilibrium price of permits σ. To determine the equilibrium price p of goods, I substitute into the market demand:

$$p = a - \sum_j x_j(p; \sigma) \;\Leftrightarrow\; p(\sigma) = \frac{a + \sigma\delta}{1 + J}.$$

The equilibrium condition for the permits price σ requires that the demand for permits, which are firms' emissions as induced by their optimal outputs, is equal to the cap L that the politician sets. This allows for the expression of the permit price σ and the market price p in terms of the cap L:

$$\sum_j \delta x_j(p; \sigma) = L \;\Leftrightarrow\; p(L) = \frac{a}{J} - \frac{L}{\delta J^2}.$$

Furthermore, firms' equilibrium output and emissions (which are all the same since firms are symmetric), are equal to

$$x^*(L) = \frac{L}{\delta J}.$$
$$e^*(L) = \frac{L}{J}.$$

Lemma 1 *Given the politician's choice of cap L, each firm produces $x^*(L) = \frac{L}{\delta J}$ which generates emissions*

$e^*(L) = \frac{L}{J}$.

Voter Decisions

Recall that individuals in district d have the following utility function:

$$U_{id}(x) = u(x) + z - D_d(E) + \varepsilon_{id}.$$

Individuals consume x based on the maximization of $u(x)$ subject to the budget constraint $px + z \leq y$, which yields the first-order condition $u'(x) - p = 0$, defining an individual's inverse demand curve. Suppose that individual utility is $u(x) = \log(x)$ such that in this setup, individuals will demand $x(p) = \frac{1}{p}$. Their indirect utility is therefore $U(x(p)) = \log(1/p) + y - 1 - D_d(E) + \varepsilon_{id}$. Without loss of generality, normalize each individual's income y to 1.

Given their consumption and their disutility from pollution, individuals must decide whether to vote for the politician or not. Normalize the utility from opposing the politician to zero. Thus individual i in district d votes for the politician if and only if $\log(1/p) - D_d(E) + \varepsilon_{id} \geq 0 \;\Leftrightarrow\; \varepsilon_{id} \geq -\log(1/p) + D_d(E)$.

Lemma 2 *Voter i in district d voters for the politician if and only if $\varepsilon_{id} \geq -\log(1/p) + D_d(E)$.*

Given the voters' decision rule, the probability that voter i supports the politician is $P(\varepsilon_{id} \geq -\log(1/p) + D_d(E)) = \frac{1}{2} + \omega_d(\log(1/p) - D_d(E))$. Then, using the fact that $E = L$ in the permit market equilibrium, total electoral support for the politician as a function of the cap is Putting things altogether yields

$$\Lambda(L) = \frac{1}{2} + \sum_d \beta_d \omega_d \Big[\log(\frac{\delta J^2}{a\delta J - L}) - \frac{L^2}{2}\Big].$$

Furthermore, given the economic equilibrium and the choices of the consumers, we can compute social welfare. Social welfare is total consumption/demand less the costs of the firm less the disutility from damage. Let $X(L) = Jx(L)$ be the total level of output supplied by firms. This can be expressed as

$$W(L) = \int_0^{X(L)} P(t)\ dt - \sum_j c(x(L)) - \sum_d D_d(E).$$

Substituting in yields

$$W(L) = \frac{2a\delta JL - L^2 J - L^2 - \delta^2 JL^2}{2\delta^2 J}.$$

Political Equilibrium

Finally, I characterize the politician's setting of the cap. Recall the politician's utility function,

$$V(L) = \alpha\Psi\Lambda(L) + (1-\alpha)W(L) + \sum_j \nu_j b_j(\bar{e}_j).$$

Applying the fact that $\sum_j \bar{e}_j = L$, the maximization problem is

$$V = \max_{(\bar{e}_1,\ldots,\bar{e}_J)} \alpha\Psi\left[\frac{1}{2}+\sum_d \beta_d\omega_d\Big[\log(\frac{\delta J^2}{a\delta J - \sum_j \bar{e}_j}) - \frac{(\sum_j \bar{e}_j)^2}{2}\Big]\right] + (1-\alpha)\left[\frac{2a\delta J\sum_j \bar{e}_j - (\sum_j \bar{e}_j)^2(J+1+\delta^2 J)}{2\delta^2 J}\right] + \sum_j \nu_j b_j(\bar{e}_j).$$

For a given firm j, the first-order condition $\frac{\partial V}{\partial \bar{e}_j}$ is

$$\alpha\Psi\sum_d \beta_d\omega_d\Big[\frac{1}{a\delta J - \sum_j \bar{e}_j} - \sum_j \bar{e}_j\Big] + (1-\alpha)\Big[\frac{a\delta J - \sum_j \bar{e}_j(J+1+\delta^2 J)}{\delta^2 J}\Big] + \nu_j b_j'(\bar{e}_j) = 0. \tag{1}$$

This means that, to pin down the equilibrium vector of free allowances (which in this case means to be able to distinguish each $\bar{e}_j$ rather than solve for a single cap L), it must be the case that

$$\nu_j b_j'(\bar{e}_j) = \nu_k b_k'(\bar{e}_k) \;\forall j,k = 1,\ldots,J.$$

The second-order condition is

$$\frac{\partial^2 V}{\partial \bar{e}_j^2} = \alpha\Psi\sum_d \beta_d\omega_d\Big[\frac{1}{(a\delta J - \sum_j \bar{e}_j)^2} - 1\Big] - (1-\alpha)\frac{J+1+\delta^2 J}{\delta^2 J} + \nu_j b_j''(\bar{e}_j).$$

The second and third terms are always negative. By Assumption 1, the first term is always negative as well, meaning that the politician's problem is globally concave. Hence the choice of free allowances is a maximum.

Lemma 3 *Free allowances are allocated to each firm j by solving Equation 1.*

The equilibrium is clearly summarized by Lemmas 1, 2, and 3. I now consider how free allowances change when district attributes change. In particular, I focus on electoral uncertainty ω_d and district size β_d. Since it is isomorphic to consider comparative statics with respect to the allowances given to firm j and the total cap. So I take comparative statics with respect to the cap.

First consider electoral uncertainty. Taking the cross-partial with respect to ω_d yields

$$\frac{\partial^2 V}{\partial L \partial \omega_d} = \alpha \Psi \beta_d \Big(\frac{1}{a\delta J - L} - L \Big),$$

which is negative if $L > 1$. If $\frac{\partial^2 V}{\partial \bar{e}_j \partial \omega_d} < 0$, then $\frac{\partial \bar{e}_j}{\partial \omega_d} \leq 0$, which means that as ω_d increases, firm j's free allowances decrease. Substantively, ω_d represents electoral certainty or salience: a large value of ω_d means that environmental policy is highly salient, and that valence shocks do not shift voter utilities very much. By contrast, a small ω_d implies that the support of the valence shock is quite large, and there is a greater amount of uncertainty about how voters in district d would vote (at least from the standpoint of a politician who can influence electoral choices by implementing cap and trade regulations). Therefore, the comparative static tells us that if $\frac{\partial \bar{e}_j}{\partial \omega_d} \leq 0$, politicians allocate more free permits when there is more electoral uncertainty in a particular district. The comparative static on ω_d can be thought of as assessing the *ex ante* "swinginess" of the district at large.

Similarly, for group size, we have

$$\frac{\partial^2 V}{\partial L \partial \beta} = \alpha \Psi \omega_d \Big(\frac{1}{a\delta J - L} - L \Big),$$

which is negative if $L > 1$. This means that if the cap is big, then making districts larger decreases the cap. A large cap means large pollution damages, and subjecting more individuals to that environmental damage decreases vote share. But if the cap is small, then the consumption effects outweigh the damages, so increasing district size would increase the size of the cap.

Proposition 1 *If $L > 1$, free allowances are decreasing in electoral uncertainty ω_d and district size β_d. If $L < 1$, free allowances are increasing in electoral uncertainty ω_d and district size β_d.*

Additional Figures and Tables

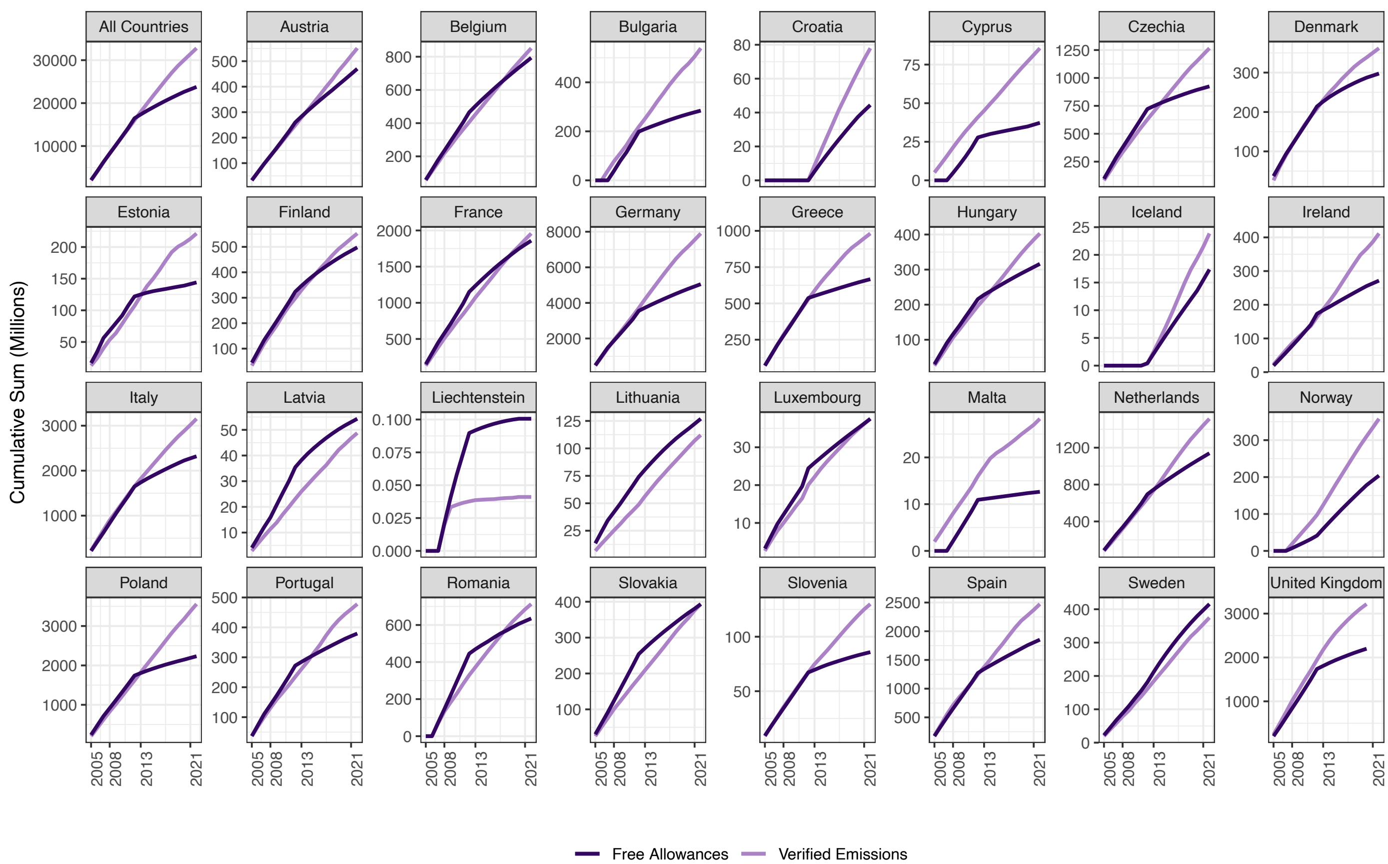

Figure A.1: Cumulative Free Allowances and Verified Emissions, 2005-2022

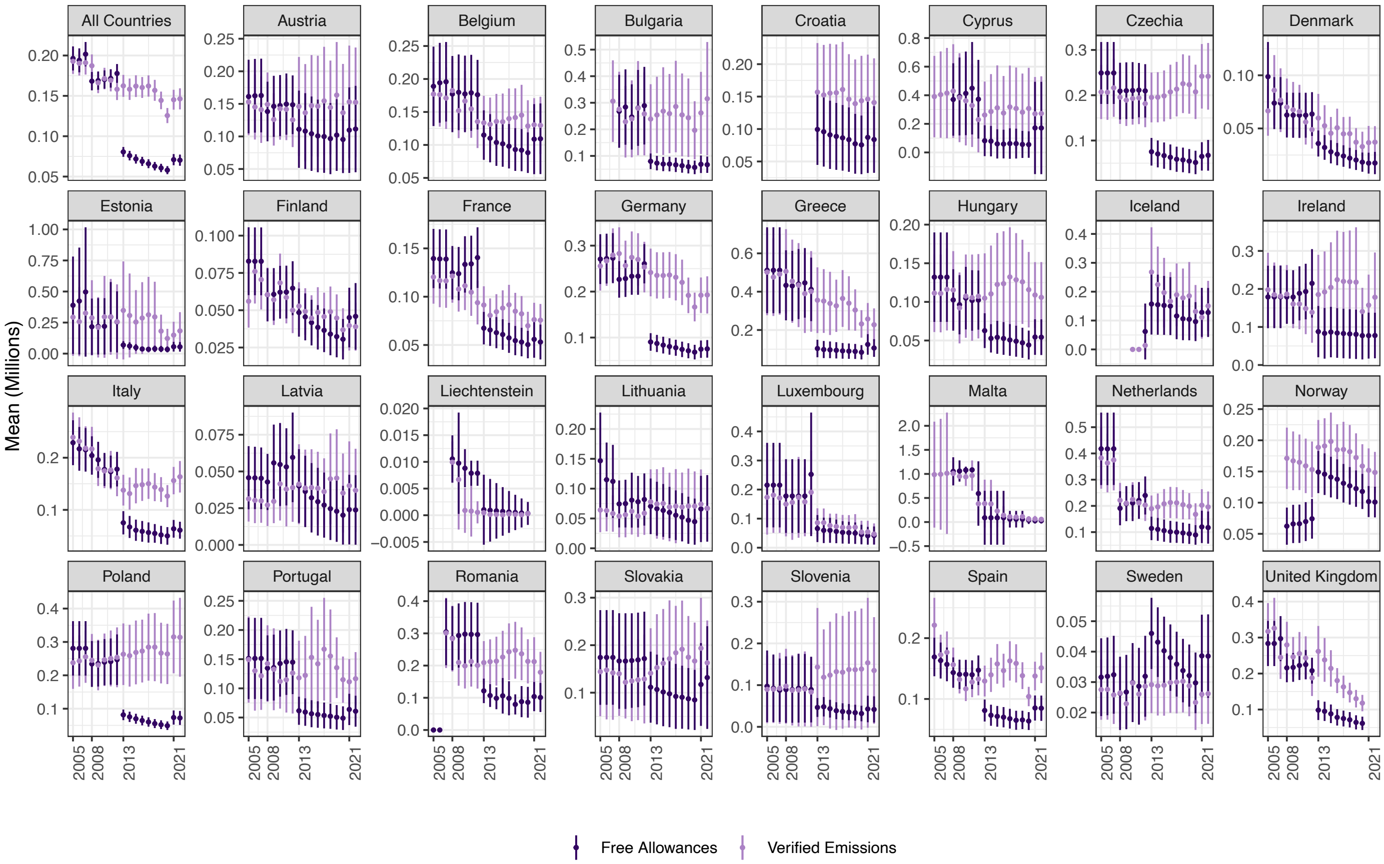

Figure A.2: Mean Free Allowances and Verified Emissions, 2005-2022

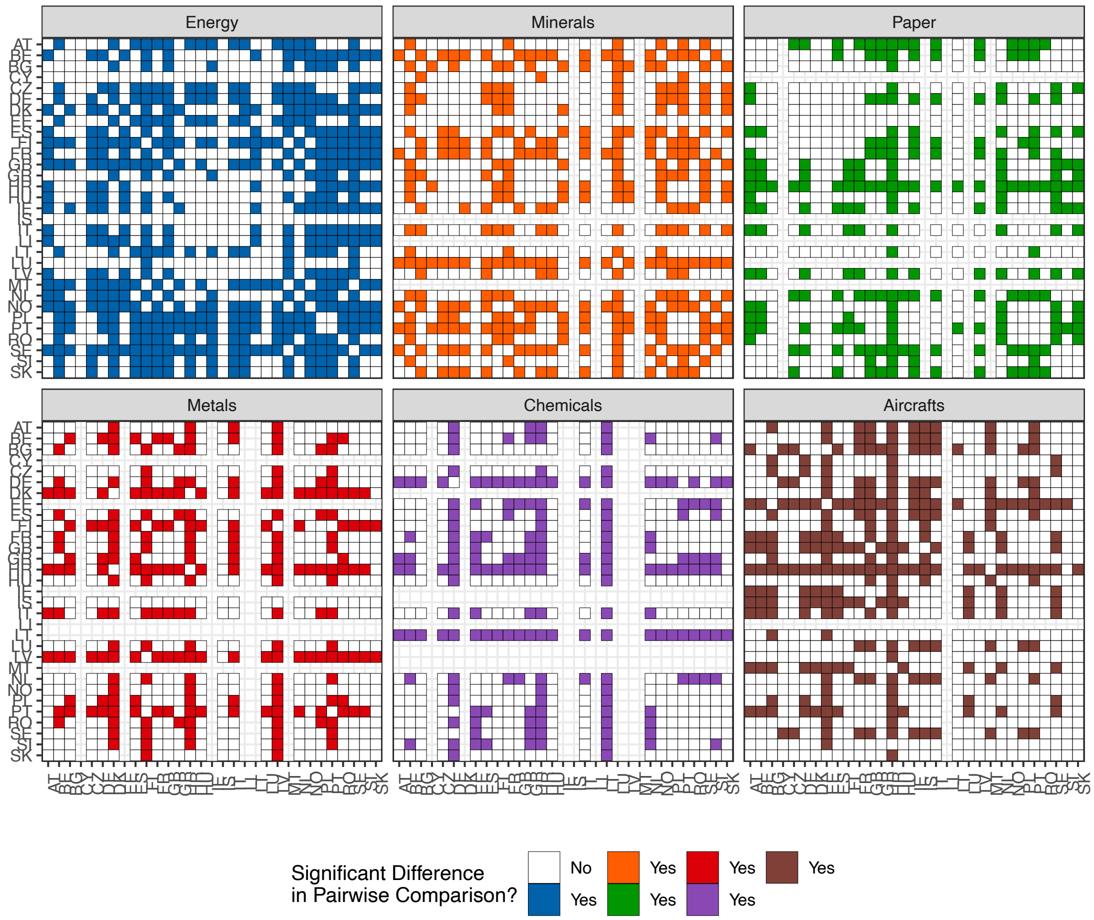

Figure A.3: Pairwise Significance Tests of Predicted Free Allowances

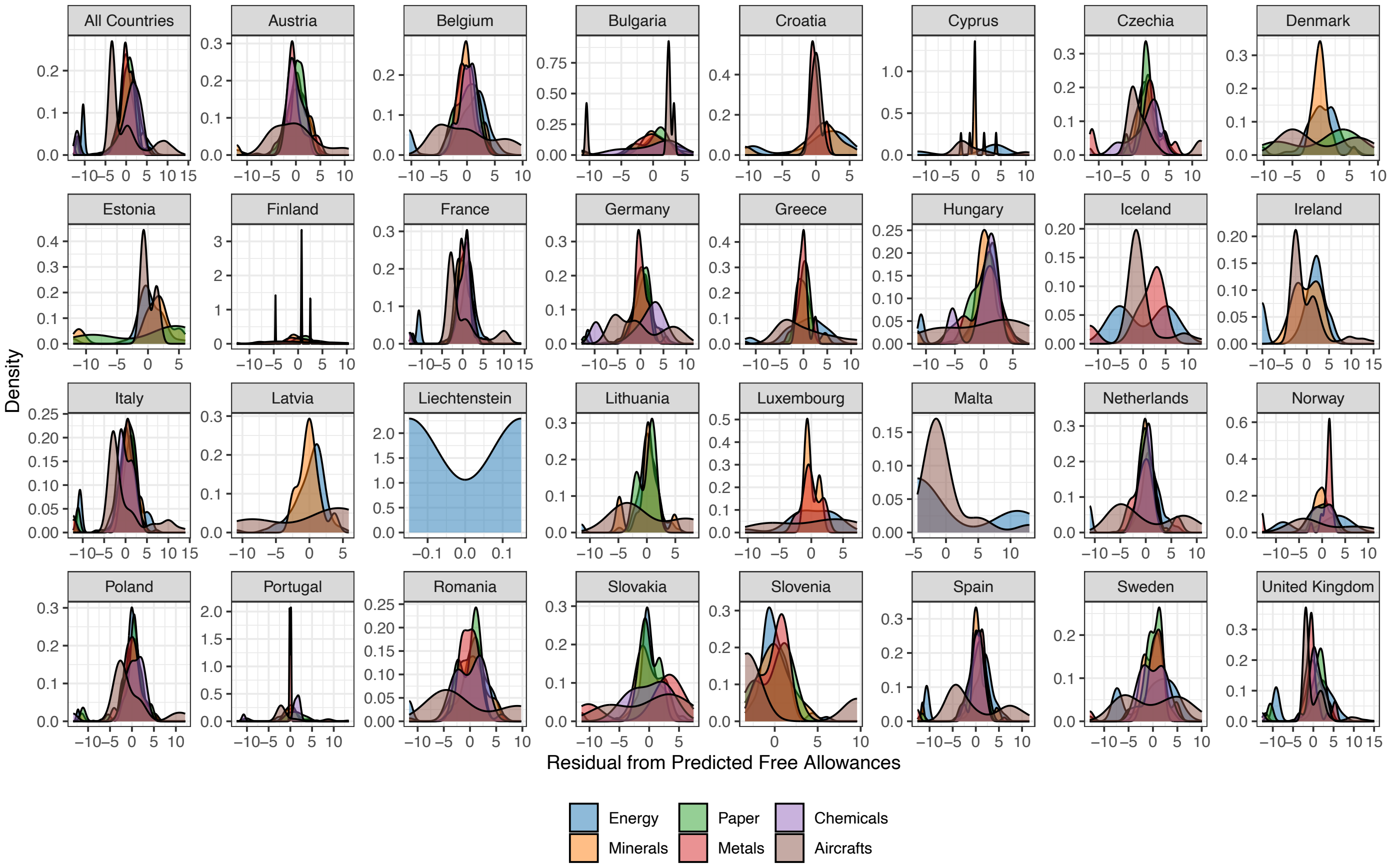

Figure A.4: Density Plots of Residuals from Predicted Free Allowances

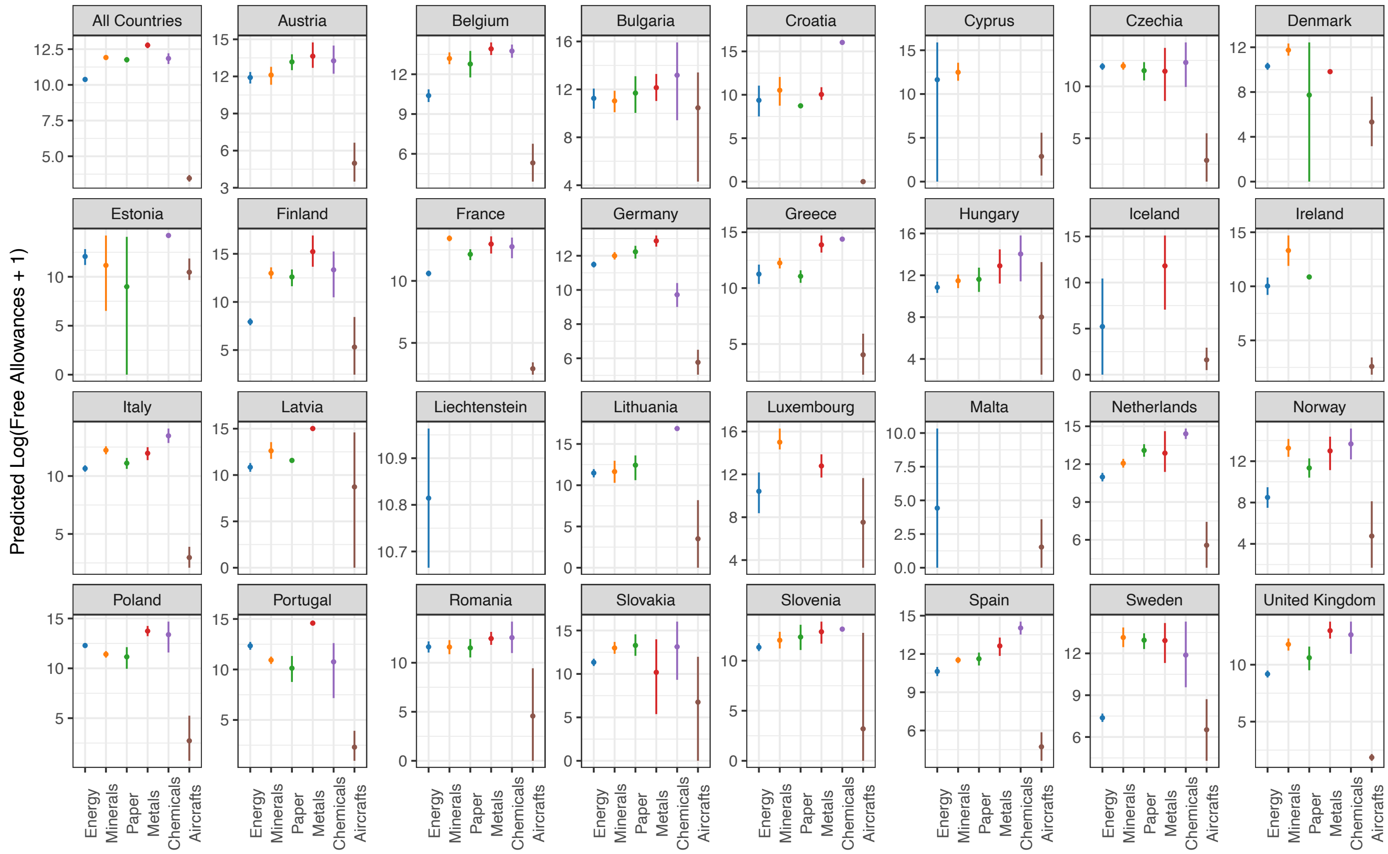

Figure A.5: Predicted Free Allowances by Sector within Countries

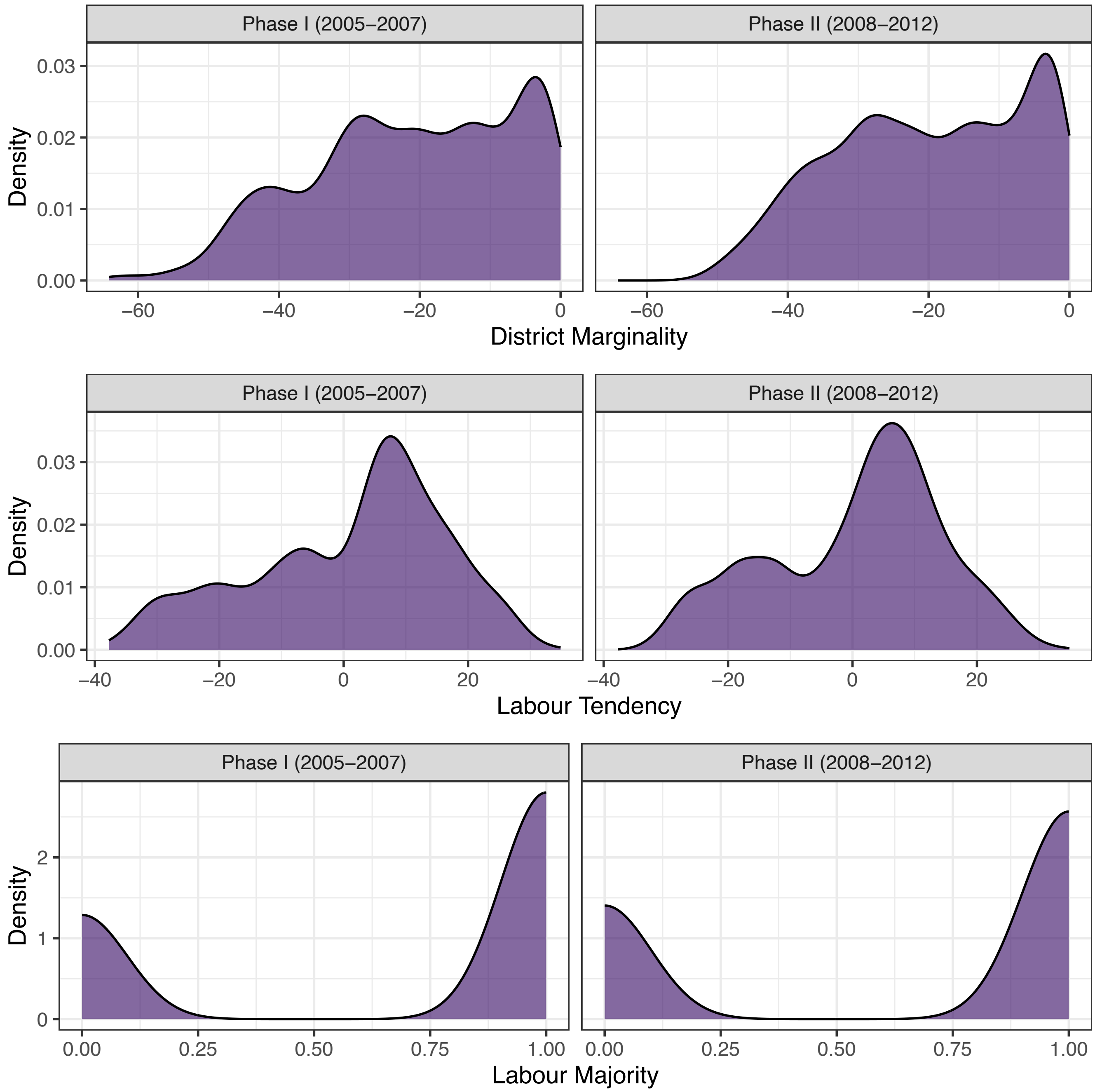

Figure A.6: Density Plots of Marginality Measures across Phases

	(1)	(2)	(3)	(4)	(5)
Marginality	0.096***	0.096***	0.025	0.011	0.017
	(0.031)	(0.031)	(0.018)	(0.013)	(0.014)
Observations	2,893	2,893	2,893	2,893	2,893
R^2	0.314	0.699	0.014	0.066	0.029
Within R^2	0.004	0.008	0.003	0.0006	0.002
Constituency fixed effects	✓				
Installation fixed effects		✓			
Sector fixed effects			✓		
County fixed effects				✓	
Region fixed effects					✓

Standard errors clustered by electoral constituency

Table A.1: Effects of Marginality on Disbursement of Free Allowances (without Trading Phase FE)

	(1)	(2)	(3)	(4)	(5)	(6)
Marginality	0.024	0.013	0.020	0.018	0.0008	0.007
	(0.019)	(0.014)	(0.015)	(0.020)	(0.018)	(0.018)
Observations	1,448	1,448	1,448	1,445	1,445	1,445
R^2	0.051	0.117	0.054	0.031	0.070	0.024
Within R^2	0.004	0.0009	0.002	0.002	2.77×10^{-6}	0.0003
Sector fixed effects	✓			✓		
County fixed effects		✓			✓	
Region fixed effects			✓			✓
Trading Phase	2005-2007	2005-2007	2005-2007	2008-2012	2008-2012	2008-2012

Standard errors clustered by electoral constituency

Table A.2: Effects of Marginality on Disbursement of Free Allowances by Trading Phase