DISCUSSION PAPERS IN ECONOMICS

Working Paper No. 24-09

Carbon Policy with External Economies of Scale

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October 25, 2024

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Abstract

World governments and multinational institutions are implementing, largely, unilateral policies to correct for negative externalities exhibited by greenhouse gas emissions. These policies take two broad forms: pricing and subsides. When crafting policy, external economies of scale should be considered as they alter the effectiveness of optimal unilateral policy. First, I provide novel estimates of the external scale factor and the carbon di-oxide abatement elasticity. Second, I show that industries that exhibit stronger agglomeration effects are also more carbon intensive. The implication for policy makers is that carbon - blind industrial policy will increase emissions, but subsides that increase the abatement cost share or reduce the reliance on emissions as an input can reduce emissions.

JEL Classification:
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1 Introduction

Industrial policy is growing in favor as a tool to mitigate the costs of climate change as it promotes growth, and when targeted, may decrease an industries emissions. Subsides that are not well targeted, however, may increase an industries emissions by boosting output without accounting for the impact of emissions. Arguments against broad based industrial policy center on the history of anti - competitive outcomes: price distortions and incentives outside of profit. These critics see a distortion of the market by the state and ask: What's the failure of the first fundamental welfare theorem? These are of course reasonable concerns to raise when billions of dollars are being appropriated - the flavor of the day being initiatives to reduce global green house gas emissions while also supporting domestic manufacturing output and employment.

The tools of modern industrial policy center on domestic subsides for specific industries and targeted tariffs on country - industry pairs, both of which place a wedge between producer and consumer prices. Returning to the first fundamental welfare theorem: our economy is pareto efficient when we have perfect competition implying that there are no externalities or market power concerns.

What externalities is modern industrial policy targeting? In the space of carbon - reducing policies there are two main factors: the negative externalities posed by greenhouse gas emissions and the positive externalities associated with industry wide agglomeration economies, or external economies of scale. The costs of human induced climate change are widely studied, motivating the current wave of spending choices. The role of agglomeration effects have long[1] been the basis of arguments for domestic industrial policies. A modern literature matches the long standing theory behind domestic subsides with data, estimating industry level values and analyzing their role in global trade. I add to this literature by estimating the size of these agglomeration effects at the country - industry level by using sub - industry variation.

A new literature, Lashkaripour and Lugovskyy (2023), demonstrates the optimal policy response of agents depends on a key correlation of two elasticities: the trade elasticity of substitution and the scale elasticity.

[1]See Chipman (1970) and Ethier (1982) for the formalization of these arguments.

This correlation is negative using my estimates, the same sign as the literature. When this market relationship is present optimal trade polices will have a limited impact and industrial policy will preform better. The negative relationship between the trade and scale elasticity means that the industries that benefit most from agglomeration effects are also the most difficult to substitute away from. When combined with the result that industries that exhibit larger external economies of scale are dirtier, policy makers need to think carefully about how best to pursue their carbon policy.

A policy maker who is attempting to reduce global emissions is then left with choice – implement a carbon tax and tariff system that may have little impact on global patterns of resource use while having a domestic impact or implement a domestic industrial policy regime that emphasizes reductions in greenhouse gas emissions. The carbon tax and tariff still reduce domestic demand for greenhouse gasses but does so in a way that limits economics growth potential, while the industrial policy incentives technological innovation and can add to economic output.

These policy choices are not just a theoretical curiosity - the European Union (EU) has long had their emissions trading system (ETS) with many other countries offering some kind of similar carbon pricing system and the United States (US), among other actors, has appropriated large amounts of public funds to subsides for the 'green transition'. The EU and US policies have the same intended goal of reducing global greenhouse gas emissions, but have chosen two opposite approaches mostly born out of political economy concerns with US carbon pricing.

I find that the relationship between industries that exhibit stronger external scale effects and their carbon output is positive both for their raw intensity and their abatement elasticity. This suggests that broad subsides for industries with high external scale effects will increase overall emissions. For industrial policy to move the system toward a lower emission state it needs to focus on increasing the abatement cost share or reducing the importance of emissions to output, failure to do so will result in higher emissions.

Section two of the paper will now move to a discussion of the related literature. A simple motivating framework is provided to inform the empirical results that will come in section three. Section four discusses the novel parameter estimates and section five provides the key empirical results. Lastly, a brief discussion is offered in section six.

2 Literature Review

The intersection of globalisation and the environment has long been a research area that generated interest. Copeland and Taylor (2004) analyse much of the earlier literature at this intersection and provide a unified framework to analyze questions relating to trade and environment that has been subsequently built on. Much of this literature has focused on the efficiency of carbon pricing combined with a carbon border adjustment mechanism, or carbon tariff. Carbon tariffs are shown to reduce global emissions in Larch and Wanner (2017) mainly by shifting the production mix both within and across countries, however, this reduction in global emissions has a trade off of lower global welfare and output.

Similarly, Kortum and Weisbach (2023) find that an optimal unilateral carbon policy contains three policy levers: a domestic price, a carbon tariff, and a good specific export subsidy. Elliot et al. (2010) study the impacts of a carbon tariff and find that the imposition of a unilateral carbon price will lead to substantial leakage, but this leakage can be fully captured with an appropriately set carbon tariff.

Farrokhi and Lashkaripour (2024) derive analytical forms for the optimal policy choice of countries and find that an optimally set unilateral carbon tariff fails to meaningfully reduce global emissions relative to a multilateral border adjustment following Nordhaus (2015), or a globally optimal carbon price. This work also studies how internal economies of scale[2] impact the effectiveness of these optimal policies by further muting their impact, albeit to a limited extent. They do find that a more granular analysis shows firms shifting toward larger markets, even those that impose a carbon price, after the implementation of a carbon tariff.

Emissions abatement plays a key role in how industries react to regulation, Shapiro and Walker (2018) use firm level data from the United States to estimate the firm level emissions reaction to changes in their level of abatement. The authors study several pollutants that are correlated with carbon dioxide (CO2), but do to data constraints they are

[2]See Krugman (1980).

unable to estimate a parameter for CO2.

Another strand of the literature has focused on the efficiency of second best policy alternatives when the first best carbon price could not be implemented for technological, political, or legal reasons. Fischer and Newell (2008) compare several policies to reduce emissions in the US electricity grid and find that the optimal path is a combination of all policies. Boehringer et al. (2010) preforms a similar exercise but for global emissions noting heterogeneity of optimal responses by industry and trading partner.

Fisher and Fox (2012) compare four different policy alternatives to combat leakage of domestic regulation and find that none of the choices substantially reduce global emissions, but do aid in protecting industries that face domestic regulation. A full border adjustment is usually most effective, but in close second is output - based rebating for key manufacturing industries. Morsdorf (2022) finds analyzes several versions of a carbon tariff and shows that the EU border adjustment will reduce leakage, but more important generate revenue that can be used to invest in cleaner technology.

A recent wave of papers in the trade literature has been examined the role of external economies of scale, or country wide industrial agglomeration effects, on the pattern of trade. Bartelme et al. (2019) discuss the classic arguments for industrial policy, the presence of the agglomeration effects, and estimates external scale parameters for a set of manufacturing industries. To understand how external economies of scale impact welfare and the pattern of trade Kucheryavyy et al. (2023) build a computable general equilibrium model of trade. They find that the introduction of external scale effects aids countries that specialize in high scale industries and aid welfare gains from trade liberalization unless it incentives a country to produce more in low scale industries.

Building on this literature is Lashkaripour and Lugovskyy (2023) who derive analytical forms for optimal trade and industrial policy. Their model suggests that optimal trade policy is ineffective at correcting industrial miss-allocation when implemented unilaterally. Unilateral industrial policy faces similar issues, but global industrial policies offer stronger welfare gains than optimal unilateral actions.

Arguments for and against industrial policy have existed for over a century[3], but a new wave of arguments for industrial policy has risen. Rodrik (2008) highlights the strong case for industrial policy theoretically, but observes that difficulty arises in the practical implementation. Discussing low - carbon industrial policy explicitly, Naudé (2011) explores the implications and feasibility of wide spread policy to support the climate transition. How governments design their green industrial policy is as important as the act of implementing it - a multilateral focus on developing economies to be robust to the impacts of climate change while also aiding them to reduce their emissions is vital.

The recent resurgence in positive views of industrial policy is motivated by subpar economic growth in the developing world as well as fears of Western governments about the rise of the Chinese economy. Aiginger and Rodrik (2020), contemplating these motivations and the recent work related to industrial policy offer a review article of the literature. Extending this review Juhász et al. (2023) review the empirical results and methods of the resurgent literature and find that arguments for industrial policy have strengthened.

3 Motivating Model

To motivate future empirical results, think about a simple model of international trade in the flavor of Eaton and Kortum (2002) building on the multi-industry framework of Costinot, Donaldson, and Komunjer (2012). This Ricardian setup is augmented with external economies of scale in the vain of Kucheravvy, Lynn, and Rodriguez – Clare (2023).

External economies of scale represent non-linearities in output for a given input of labor. They can be motivated by more efficient supply chains, human capital spillovers, or advantageous natural resource endowments for example. When external economies of scale are present, a given industry becomes more efficient across a country for a given amount of labor. This compares directly to internal economies of scale which instead measure how an individual firm becomes more efficient as it grows in output.

External economies of scale then act as country wide agglomeration

[3]See Pigou (1920), Marshall (1920), and Graham (1923).

effects for a given industry[4]. These agglomeration effects offer a motivation for wide scale subsidy programs that target broad based industries rather than specific firms. In the context of carbon policy, the inclusion of the agglomeration effects is vital to understanding how green industrial and trade policy will impact the economy.

3.1 Unique Assumptions

3.1.1 Pollution

Emissions in this framework follow the form of Shapiro and Walker (2018) where firms emit pollution as they produce goods, but augmented to include external economies of scale for labor. Modelling choices for pollution vary depending on data availability and research question[5]. This framework assumes that each unit of production emits z units of emissions as:

$$z_{ij}^k = (1 - a_i^k)^{\frac{1}{\alpha^k}} (l_{ij}^k)^{\phi^k} \tag{1}$$

Where a_k represents the level of pollution abatement undertaken industry k and α^k is the Cobb-Douglass share for pollution emissions[6]. The units of labor required to produce the flow of good from country i to country j is l_{ij}^k and ϕ^k is the external scale factor for industry k.

There is a tension between two parameters in the pollution emissions - an increase in external scale factor increases the level of pollution for a given labor allocation while an increase in the abatement elasticity decreases the level of pollution for a given level of abatement. The sign

[4]For example, the chemistry industry will be able to produce more than double the output if their labor allocation were to double as they benefit from various efficiencies.

[5]A major difference in modelling choice is made on how emissions enter the system: as a by - product of production or as an input to production, either as energy or direct emissions. Larch and Wanner (2017) and Farrokhi and Lashkaripour (2024) both use energy as an input. Using energy as an input precludes one from the break down of emissions by scale, composition, and technique effects as done in Copeland and Taylor (2004), but offers insights about global energy markets.

[6]There are several simultaneous interpretations of α^k, when I estimate it later it is the elasticity between intensity of output and share of total capital expenditure spent on abatement activity. Shapiro and Walker (2018) and Copeland and Taylor (2004) discuss these different interpretations.

of this empirical relationship is important for policy makers to consider as it will impact the effectiveness of policy to alter emissions.

If industries that benefit from large external scale effects share a negative correlation with the inverse abatement elasticity - then poorly designed industrial policy may lead to an increase in emissions. By boosting output in these industries, something that is efficient economically, policy makers will induce increases in emissions as the external economies of scale favor dirtier industries. The opposite is true when the two parameters are negatively correlated. I will return to this discussion after estimating the key paramters.

3.1.2 Policy Set

Policy makers have two choices: a carbon tariff or border adjustment mechanism, combined with a domestic carbon price, and domestic industrial subsides. A domestic price and border adjustment account direct emissions costs of production. A subsidy that promotes carbon abatement, by funding carbon reducing R&D projects or by otherwise offering incentives to domestic firms to reduce their carbon emissions, boosts firms in the chosen industries. Farrokhi and Lashkaripour (2024) describe the optimal policy response for this class of trade models and polices.

These policy choices create a wedge between producer and consumer prices in two ways:

$$\hat{P}^k_{ji} = \frac{1 + t^k_{ji}}{(1 + s^k_j)} P^k_{ji} \quad \textit{and} \quad P^k_i = P^0_i + \tau^k_i \tag{2}$$

The import tax is t^k_{ji}, s^k_j is the industrial subsidy, and τ^k_i is the domestic carbon price. The policy choices work to internalize the externalities of the system so that the general equilibrium will reach an efficient outcome. The optimal policy is then given as:

$$\tau^*_i = \hat{\delta}_i, \quad s^{*k}_i = \frac{1}{\phi^k - 1}, \quad t^{*k}_{ji} = \bar{t}_i + \frac{1 - \phi^k}{\phi^k} \tau^*_i v^k_i, \quad t^0_{ji} = \bar{t}_i \tag{3}$$

where $\hat{\delta}_i$ is the marginal social cost of carbon emissions, ϕ^k is the external scale factor, and $\bar{t}_i$ is an arbitrary tax shifter.

The unilaterally optimal policy response captures all of the key policies, but does so in a way that offers carbon blind industrial policy. This is because a domestic carbon price is assumed that will internalize the negative externality causing the domestic subsidies to be appropriately sized. European Union policy makers can then rely on this set of policies, but countries pursing green industrial policy without a domestic carbon price, like the United States, may increase their emissions if they do not design their industrial policy in key ways. The implications of policy design will be discussed more heavily in section five.

4 Parameter Estimates

In the following sections I describe the methodology to estimate the two key model parameters: the external scale factor and the abatement elasticity. Directly relating to equation (1), these parameters dictate the level of emissions for a given level of labor input and abatement cost share, as well as influence the optimal policy schedule.

4.1 External Scale Factor

To estimate the scale elasticity, I use within industry data to estimate the parameter at the country – industry level. This is more granular than what has been estimated in the related literature which is only at the industry level. I also rely on estimating this parameter by year, while the related literature has utilized a dynamically constant value.

The main estimating equation is:

$$\frac{1}{\theta^k} ln(X^h_{ij,t}) = \phi^k_{i,t} ln(L^h_{i,t}) + \eta_{ij,t} + \eta^h_{j,t} + \epsilon^k_{ij,t} \tag{4}$$

Where $\pi^k_{ij,t}$ is the trade share between countries i and j in year t for industry k, θ^k is the elasticity of substitution, $L^k_{I,t}$ is the labor allocation to industry k in country i for year t. In addition, bilateral – year and exporter – year – industry fixed effects are included. This specification follows from Bartelme et al. (2024) but is updated to fit my level of industrial variation.

4.1.1 Instrumented Demand

Due to endogeneity concerns between sector size in each country and demand for goods in that country, I use an instrumental variable approach to remove bias from my results. The two stage least squares (2SLS) approach predicts demand in each country by first estimating the price index:

$$\frac{1}{\theta^k} ln(x^k_{ij,t}) = \eta^k_{i,t} + \eta_{ij,t} + \eta^k_{j,t} + \epsilon^k_{ij,t} \tag{5}$$

where θ^k is the trade elasticity of substitution for industry k and x^k_{ij} is the trade flow from country i to country j in industry k for year t. Exporter-year-industry, importer- year-industry, and bilateral pair fixed effects are also included.

The estimated price index is given as:

$$\hat{P}^h_{j,t} = exp(\hat{\eta}^h_{j,t})$$

The first stage regression predicts the estimated price index:

$$ln(\hat{P}^h_{j,t}) = \sum_s \beta_s 1_{s=h} * ln(\bar{L}_{j,t}) + \tilde{\eta}_{j,t} + \tilde{\eta}^h_t + \tilde{\epsilon}^h_{j,t} \tag{6}$$

A set of instruments are constructed by interacting $\bar{L}_{j,t}$, country j's population in year t, with a set of industry indicators. Importer - year and industry - year fixed effects are included. $1_{s=k}$ is an indicator function the event s = k. For this to be a valid instrument it must satisfy the exclusion restriction that countries with large populations do not have greater demand in some industries than others, compared to smaller countries.

The second stage regression comes from the CES preferences assumed in equation .

$$ln(x^h_{j,t}) = (1-\rho)ln(\hat{P}^h_{j,t}) + \eta_{j,t} + \eta_{h,t} + \epsilon^h_{j,t} \tag{7}$$

Where ρ is the elasticity of substitution across manufacturing sectors and represents the size of the returns to scale present in markets. Importer- year and industry year fixed effects are also included. The IV estimate $\rho =$ is smaller than the OLS estimate of $\rho =$ which indicates stronger returns to scale exist after instrumenting for sector size in accordance with prior estimates.

4.1.2 Sector Size

The key variable on the right hand side of equation is sector size, $L^h_{i,t}$. As discussed before, there are endogenity concerns due to the fact that sector size is likely to be correlated with sector demand. The 2SLS process described above works to predict an instrumented demand that can be used to create an instrument for sector size.

To recover the instrumented share of demand in industry k for country j , one needs to exponentiate the residual. To recover the sector size parameter this share is multiplied by country i's population, $\bar{L}_j$.

The definition for instrumented sector size is given as:

$$\hat{D}^h_i \equiv exp(\hat{\epsilon}^h_{i,t})\bar{L}_i \tag{8}$$

For OLS regressions, I use the following definition of sector size:

$$L^k_i \equiv \frac{\sum_j X^k_{ij}}{\sum_{k'}\sum_j X^k_{ij}}\bar{L}_i = \frac{x^k_j}{\sum_{k'} x^{k'}_j}\bar{L}_i \tag{9}$$

Where $\bar{L}_i$ is a country's population taken from the Penn World Tables version 10. The logic of these two variables is the same - a sector's size in country i is the share of total demand, domestic and foreign, times the country's population. In the OLS version, the demand share is explicitly observed in the data while the 2SLS version predicts the demand share in each industry. While not all members of the population work, population and labor force are strongly positively correlated.

4.1.3 Estimation

To estimate the scale parameter I use data from third revision of the INSTAD database[7] on country level employment data at the 4 – digit ISIC industry specification and COMTRADE[8] bilateral trade flow data at the 4 – digit HS industry specification to estimate a country – industry parameter at the WIOD industry level. Using concordance tables, I match the HS industries to ISIC and then aggregate these to the WIOD level.

The specification in equation (3) implicitly assumes that all sub - industries h within broader industry k have the same trade elasticity of substitution. The values for the trade elasticity of substitution, θ^k, are taken as the median of the literature[9].

By exploiting within country variation in sub-industries I can obtain a country level estimate of scale elasticities. This allows for two things: more granular variation in a future result and analysis of country specific patterns in external economies of scale themselves[10].

The main parameter of interest, the external scale factor, is $\phi^k_{i,t}$. I estimate the value for both a static and dynamic interpretation. Table 1 shows the static estimate for all industries while a breakdown of dynamic and country heterogeneity is featured in appendix A. These estimates are largely in line with the prior literature, however, the instrumented estimates are systemically larger than the baseline specification contrary to Bartelme et al. (2024).

4.2 Abatement Elasticity

An integral element of the model is the degree to which spending on abatement reduces emissions. The abatement elasticity, α^k, has long been present in models of international trade and the environment. I provide

[7]UNIDO, 'UNIDO Statistics Portal', https://stat.unido.org/

[8]https://comtradeplus.un.org

[9]Estimates are from Shapiro (2016), Bagwell et al. (2021), Caliendo and Parro (2015), and Giri et al. (2021)

[10]While not a first result, there are some interesting patterns in the scale parameter. They include a positive relationship with real GDP. This also may have deep implications for the efficacy of industrial policy in various countries – primarily that it has larger benefits in already wealthy countries.

Table 1: External Scale Estimates: All Years

	(1) OLS	(2) 2SLS
Food, Beverages and Tobacco	0.122***	0.142***
	(0.0139)	(0.0121)
Textiles	0.0377***	0.0678***
	(0.00913)	(0.0128)
Wood Products	0.0491***	0.0711***
	(0.00730)	(0.00808)
Paper Products	0.0421***	0.0638***
	(0.00994)	(0.0158)
Coke/Petroleum	-0.00592	0.0906***
	(0.00616)	(0.00904)
Chemicals	0.120**	0.176***
	(0.0312)	(0.0295)
Rubber and Plastics	0.106**	0.148**
	(0.0285)	(0.0390)
Other non-Metallic Minerals	0.0709***	0.103***
	(0.0107)	(0.0137)
Basic and Fabricated Metals	0.0332***	0.0593***
	(0.00540)	(0.0118)
Machinery	0.0446***	0.0864***
	(0.00609)	(0.0116)
Electrical and Optical Equipment	0.0455***	0.0582***
	(0.00623)	(0.00632)
Transport Equipment	0.0343***	0.102***
	(0.00785)	(0.0143)
Observations	8,320,645	8,320,645

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

novel estimates of the abatement elasticity by modifying the method of Shapiro and Walker (2018)[11]. I utilize the same data and structure that they do, but use an additional measure of environmental policy stringency by country to provide another source of variation. Doing this allows for me to estimate a parameter across countries and time in a balanced panel setting, rather than a long difference estimate for firms in the United States.

4.2.1 Environmental Policy Stringency

Country specific policy stringency enters as γ_{it}^{ν}, which is defined as the following ratio in country i and year t:

$$\gamma_{it}^{\nu} = \left(\frac{PolicyStringency_{it}}{PolicyStringency_{(USA)(1990)}} \right)^{\nu} \tag{10}$$

Data on Policy Stringency comes from the UNCTAD database as the Environmental Policy Stringency Index[12]. It aggregates more than 300 policy actions into an index of environmental policy stringency. The list of policy actions are all related to curbing greenhouse gas emissions, making this measure a direct comparison of countries various levels of climate change mitigation. While not all policies are implemented, or equal, this measure provides some semblance for how much a country cares about decreasing their carbon emissions.

The policy stringency measure provides information about the importance a country places on climate mitigation, but it is unlikely to have a linear relationship with abatement cost share. I introduce the parameter ν to allow for a nonlinear relationship between policy stringency and abatement cost share.

To calibrate a value for ν, I use my method to estimate the abatement elasticity for the same pollutants as Shapiro and Walker (2018). Taking their estimates as true, I choose ν such that my estimates for these mutual

[11] Shapiro and Walker (2018) estimate this parameter for several pollutants in the United States, but they do not recover a parameter for CO2 due to data constraints.

[12] OECD (2024), "Environmental policy: Environmental Policy Stringency index", OECD Environment Statistics (database), https://doi.org/10.1787/2bc0bb80-en

pollutants are roughly equivalent[13]. Table B.1 shows the mean difference of α^k for the other pollutants (carbon monoxide, nitrogen oxides, sulfur oxides, and volatile organic compounds) which my data overlap Shapiro and Walker (2018). My method returns systemically larger magnitudes and achieves a minimum difference around $\nu = 0.05$.

4.2.2 Abatement Cost Share

The air abatement cost share is defined for only the United States in 1990 due to data constraints[14]. I utilize the data from 1993 PACE Survey[15] of firms, which asks how much firms spend on their total pollution abatement across several mediums: air, water, solid waste, and other. The air abatement cost share then describes the share of a firm's total capital expenditure, taken from the US Annual Survey of Manufactures, that was spent on emissions abatement through the air medium. The air abatement cost share, $a^k_{USA,1990}$, is defined as:

$$a^k_{(USA)(1990)} = \frac{Air\ Abatement\ Cost^k_{USA,1990}}{New\ Capex^k_{USA,1990}} \tag{11}$$

The PACE survey is at the firm level, but the data is restricted to use in US Census research data centers. The publicly available data is aggregated to the industry level, which I match to the manufacturing industries in the World Input - Output Database. Coverage in only the manufacturing industries is no issue as these are the industries with external scale factors.

Air emission abatement was guided by US legislation – primarily the 1970 and 1990 Clean Air Acts. Abatement expenditures are correlated geographically with areas that were ruled in non-attainment of US regulator air pollution levels. This is no issue as I aggregate all cost shares

[13] I attempt to estimate this parameter directly using only the US abatement cost share and policy stringency, unfortunately severe data constraints make this impossible.

[14] Data exists for 1991 and 2005, but does not provide meaningful variation. Because I use policy stringency for the time element I do not use the 2005 data in my main estimation. It is used in an attempt to estimate the parameter ν but a lack of power prevents this from being a reliable estimate

[15] US Bureau of the Census; Current Industrial Reports; MA200(93)-1; Pollution Abatement Costs and Expenditures, 1993; US Government Printing Office; Washington, DC; 1994.

across the United States and all policy stringency shifting is done relative to the policy level in the United States in 1990.

4.2.3 Estimation

The estimating equation is:

$$ln(\frac{CO2^k_{it}}{Output^k_{it}}) = \frac{1-\alpha}{\alpha} ln(1 - a^k_{(USA)(1990)} * \gamma^{\nu}_{it}) + \eta_i + \eta_k + \epsilon^k_{it} \tag{12}$$

Which includes country and industry fixed effects.

To estimate industry level values, I scale α by the relative pollution per dollar cost in industry k[16]. This preserves the mean of all industries as the estimated α but provides variation across industries. Some industries emit more pollution for a given input cost, and these will have relatively higher values for their abatement elasticity.

These estimates suffer from measurement error which biases β to zero and α toward 1 - these can be interpreted as an upper bound for α.

Table 2: $\alpha = \frac{1}{\beta+1}$

	(1)	(2)	(3)
	$\rho = 0.03$	$\rho = 0.05$	$\rho = 0.1$
$ln(1 - a^k_{(USA)(1990)} * \gamma^{\rho}_{it})$	21.73**		
	(7.702)		
$ln(1 - a^k_{(USA)(1990)} * \gamma^{\rho}_{it})$		22.03***	
		(6.004)	
$ln(1 - a^k_{(USA)(1990)} * \gamma^{\rho}_{it})$			15.56***
			(3.555)
Implied α	0.0439	0.0434	0.060
Observations	5840	5840	5840

Standard errors in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

[16]I use the same relative pollution per dollar cost values as Shapiro and Walker (2018)

Table 3: α^k

Industry	$\rho = 0.03$	$\rho = 0.05$	$\rho = 0.1$
Food, Beverages and Tobacco	0.0147	0.0145	0.0202
Textiles	0.0081	0.0081	0.0112
Wood Products	0.0383	0.0377	0.0525
Paper Products	0.0829	0.0818	0.1138
Coke/Petroleum	0.0787	0.0777	0.1081
Chemicals	0.0761	0.0751	0.1045
Rubber and Plastics	0.0177	0.0175	0.0243
Other non - Metallic Minerals	0.1129	0.1114	0.1551
Basic and Fabricated Metals	0.1072	0.1058	0.1472
Machinery	0.0056	0.0055	0.0077
Electrical and Optical Equipment	0.0058	0.0053	0.0074
Transport Equipment	0.0064	0.0064	0.0089
Misc. Manufacturing	0.0173	0.0171	0.0238

The values of which indicate that there are decreasing returns to effects of environmental policy on pollution abatement – doubling of a countries policy stringency does not double the abatement cost share. This makes intuitive sense from looking at a marginal abatement cost curve – the first and easiest abatement choices for a firm have negative or low costs while the remaining options have increasingly higher costs. I assume that all non-manufacturing industries do zero abatement.

5 Empirical Results

When accounting for external economies of scale, inadequate industrial policy will fail to allocate resources efficiently as industries exhibit positive externalities from an increase in the size of the labor force allocated. This means that governments should be subsidizing these industries, regardless of the effects on climate mitigation, to correct for a market failure. Targeted industrial subsides are then the efficient policy choice.

The work of Bartelme et al. (2024) and Kucheryavyy et al. (2023) has shown that external economies of scale influence the pattern of international trade, albeit to a limited extent beyond the numerous other factors well known to the literature. Related work such as Lashkaripour and Lugovoskyy (2023) show that when the market setting is such that there is a negative correlation between the trade elasticity of substitution and the external scale factor, optimally set trade policy will have limited impact.

The other relevant policy choice is a carbon tariff. A carbon tariff on the embedded carbon of all imports is a straightforward and logical reaction to the negative impacts of carbon leakage[17]. However, if a carbon tariff has limited impact on demand in the highest emission industries, then it may fail to achieve domestic emission reduction goals while imposing higher costs on consumers. The carbon tariff would make domestic industry more competitive as it would level the playing field with respect to carbon costs.

When considering how governments should best mitigate the impacts of climate change, optimal policy choices care about the pattern of carbon intensity and external economies of scale – do high scale industries display higher or lower carbon intensities? If the correlation between scale and intensity, defined as tons of CO2 emitted per unit of real output, is positive then the industries that would benefit the most from government based industrial policy are also relatively dirtier. With well-crafted and targeted industrial subsidies, policy makers may realize additional positive externalities by reducing the carbon emissions of dirty industries. This twofold positive impact makes green industrial subsidies an interesting tool in mitigating global emissions. However, poorly designed green industrial policy will only increase domestic emissions.

A second key model parameter relationship exists between the external economies of scale and the abatement elasticity. As seen in equation (1), a high scale industry will emit more pollution for a unit of labor and an industry with with a high abatement elasticity will emit less. The abatement elasticity and the carbon intensity of an industry are closely related[18], so these regressions should move in the same direction. The second regression helps illustrate the tension between abatement elasticity and external scale factor in equation (1).

[17]Carbon leakage is generally viewed as the shifting of carbon emissions to foreign markets in response to a domestic carbon price, it can also be seen through the lens of diffusion of lower emissions technology as discussed in Morsdorf (2022).

[18]The coefficient between the two logged variables is 0.89 with intensity as the dependent variable and 0.51 with the dependent variable as abatement elasticity, including country and year fixed effects. Both are extremely precise.

5.1 Carbon Intensity and External Scale Factor

Returning to our real-world setting, carbon tariffs will have a limited ability to alter the patterns of trade in key industries. They will alter domestic consumption choices but will do little to influence foreign producers without carbon pricing due to an inelastic demand in global markets and the classic small market effect[19]. The policy will then achieve the goal of internalizing the negative costs associated with carbon emissions for domestic production, but will also impose costs on society while having a limited impact on global emissions.

Industrial policy would also benefit domestic producers and could be highly focused on projects that reduce overall emissions. While still imposing costs on society, there is parallel investment that occurs to promote economic growth. External scale factors represent the lost benefits to society of not subsidizing the industry, so these are industries that would be moved toward a more efficient outcome.

5.1.1 Specification

The main estimating equation is:

$$ln(\frac{CO2_{it}^{k}}{Output_{it}^{k}}) = \beta ln(EES_{it}^{k}) + \eta_k + \eta_i + \eta_t + \epsilon_{it}^{k} \tag{13}$$

With carbon intensity of real output as the dependent and external scale factor as the independent variable. The unit of observation is at the country - year - industry level and country, year, and industry fixed effects are included. This means that the coefficient can be interpreted as the average effect for a given country - year - industry observation.

5.1.2 Estimate

Table 4 shows the estimates from estimating equation (12). The magnitudes of both estimates of the external scale factor are positive, but rather muted. This indicates that a 10% increase in the instrumented

[19] See Brunel and Levinson (2024).

scale factor is associated with a 0.65% increase in carbon intensity. This weakly suggests that industries with larger scale factors are also dirtier. The implication for policy is that optimal industrial policy will increase emissions as it would be targeted in high - carbon industries.

Table 4: Stronger EES is associated with Dirtier Output

	(1)	(2)
	ln(Intensity)	ln(Intensity)
OLS	0.0136	
	(0.0303)	
2SLS		0.0647*
		(0.0319)
Observations	5663	5829

Robust standard errors in parentheses. Level of observation is country, year, and industry.
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

5.2 Abatement Elasticity and External Scale Factor

The abatement elasticity is another measure of industry dirtiness where a higher value implies more reductions in emissions from a given level of abatement. This variable is only estimated at the industry level due to data and methodology constraints, but this relationship has a direct link to equation (1). The two things that impact pollution in a given industry are size of output and level of abatement.

Output is positively increasing with the external scale factor meaning industries that exhibit strong scale factors, and therefore optimal policy says should be subsidized, are inherently going to produce more emissions for a given level of labor input. The level of abatement is inversely driven by the abatement elasticity implying that high emissions industries need to expend more resources on abatement to reduce their level of emissions by the same amount as a low emission industry.

The relationship of these two variables will help inform how best to structure industrial policy that cares about emissions. If the scale and inverse abatement elasticities share a negative relationship, than industries where agglomeration plays a stronger role are dirtier. This would confirm the prior regression results, but through a more motivated manner. Due to data and methodology constraints, the abatement elasticity can only be estimated at the industry level so only a simple scatter plot of the 12 industries is provided.

Figure 1: 2SLS

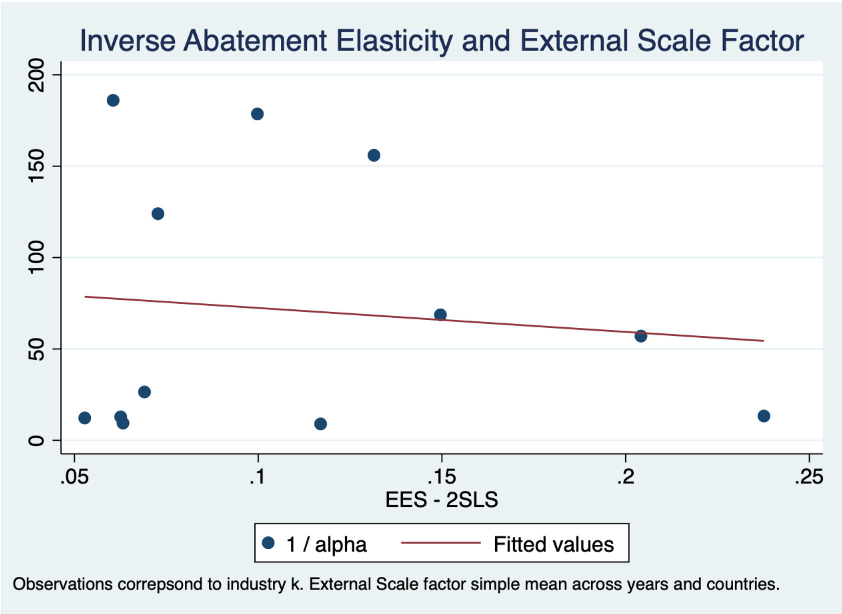
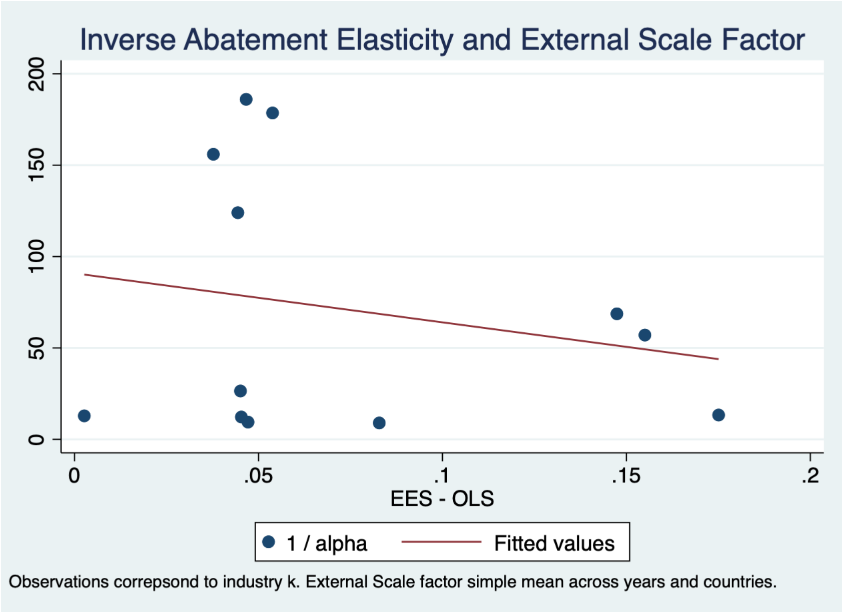


Figure 2: OLS



Figures 1 and 2 show the relationship of the inverse abatement elasticity and the external scale factor. There is a negative relationship between the two parameters indicating that for larger scale factors there is a lower inverse abatement elasticity. Referring to equation (1), the inverse abatement elasticity operates on an object with possible values between 0 and 1 so a smaller inverse abatement elasticity implies more pollution. This indicates the same pattern seen in table 4 but for key model parameters.

6 Conclusion

Industrial policy is predicated on the role of country wide industrial agglomeration effects that induce a positive externality to their production. The correction for this market failure is a broad based subsidy dependent on the size of the industries external scale factor. I first estimate a more granular version of the external scale elasticity than the literature by exploiting sub - industry variation. Doing this allows for an estimate at the country - industry - year level versus the prior industry - year estimates. The external scale factor broadly tracks the prior literature in terms of magnitude and industrial pattern.

Another key element to understand the implications of industrial policy on emissions is the abatement elasticity. The level of emissions increase as this parameter increases, so understanding the relationship between the this and the external scale factor is vital. The prior literature does not estimate this parameter for carbon di-oxide, so I provide novel estimates by utilizing industry variation in the United States and environmental policy variation globally.

With these novel estimates, I find that the relationship between industries that exhibit stronger external scale effects and their carbon output is positive both for their raw intensity and their abatement elasticity. This suggests that optimal policy, broad subsides for industries with high external scale effects, will increase emissions. This means that for industrial policy to move the system toward a lower emission state it needs to focus on increasing the abatement cost share and failure to do so will result in higher emissions. The parameter ^{k} is estimated as the abatement elasticity, but also represents the Cobb - Douglass share of emissions so industrial policy may also be crafted in a way that reduces the importance of emissions in the output function. Industrial policy that is blind to emissions will increase emissions both by increasing output and focusing on the dirtiest industries, but targeted policy can achieve efficiency goals while also reducing emissions.

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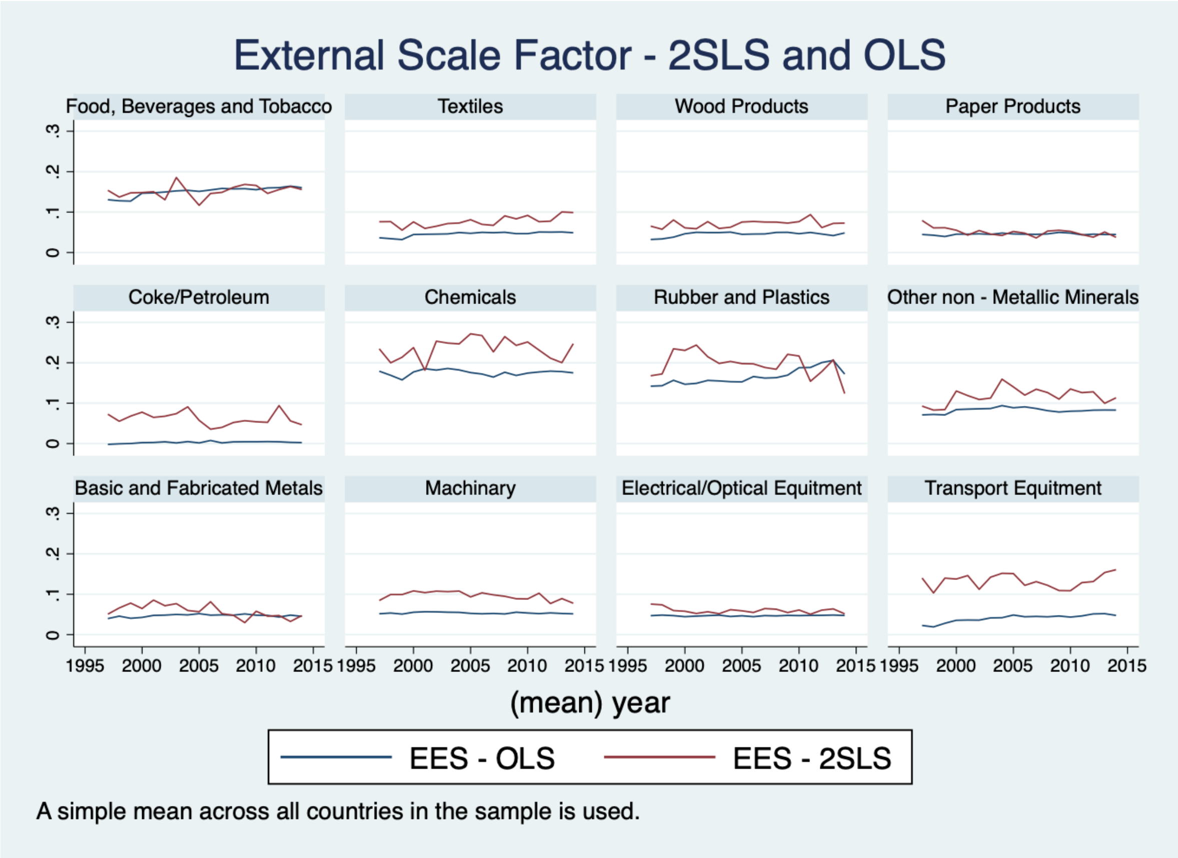
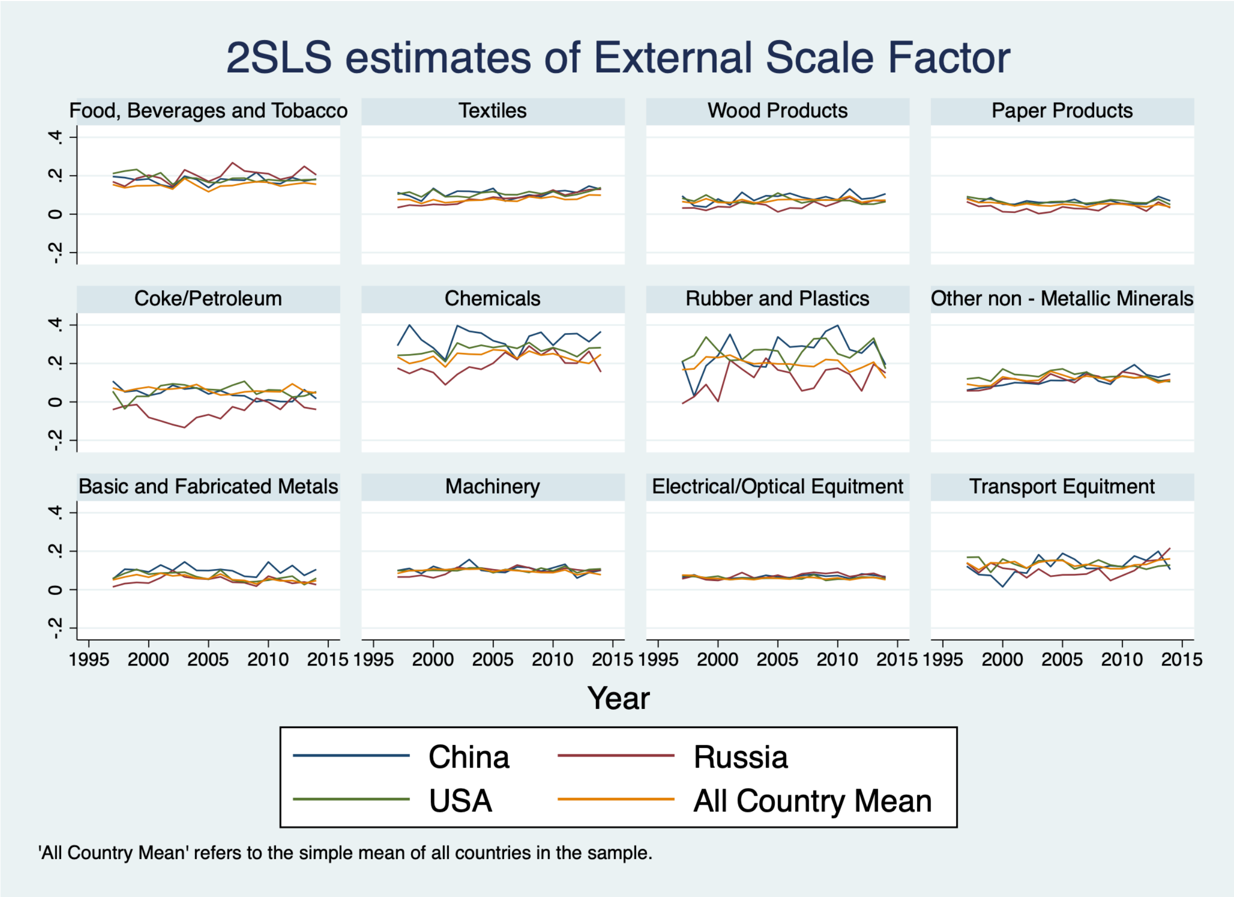
Appendices

A External Scale Factor

A.1 EES by Industry



A.2 2SLS Country - Industry Variation



A.3 OLS Country - Industry Variation

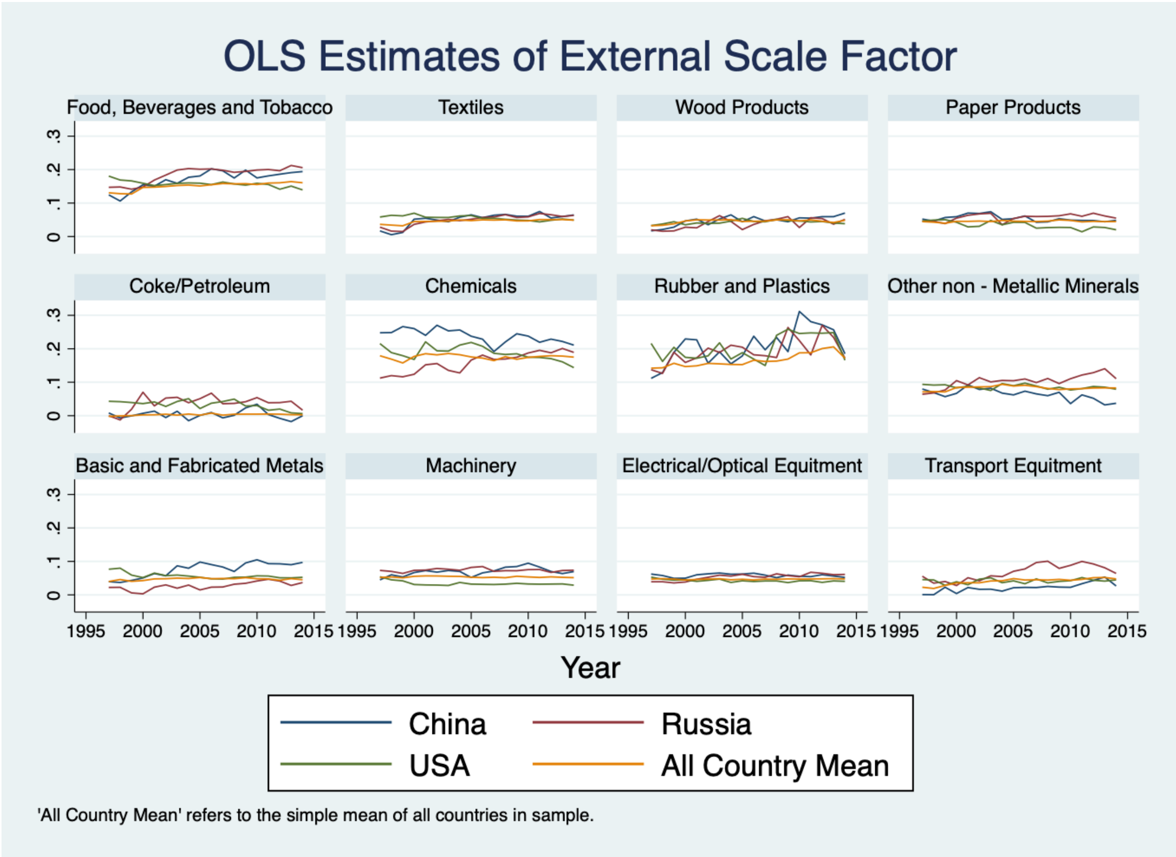


Table 5: α^k Sensitivity

Pollutant	Mean Ratio
CO: $\rho = 0.03$	2.32
CO: $\rho = 0.05$	2.27
CO: $\rho = 0.1$	3.19
NOX: $\rho = 0.03$	2.73
NOX: $\rho = 0.05$	2.64
NOX: $\rho = 0.1$	3.64
SOX: $\rho = 0.03$	1.73
SOX: $\rho = 0.05$	1.82
SOX: $\rho = 0.1$	2.67
VOC: $\rho = 0.03$	1.07
VOC: $\rho = 0.05$	1.15
VOC: $\rho = 0.1$	1.75

B Abatement Elasticity

B.1 Comparison to Shaprio and Walker (2018)