DISCUSSION PAPERS IN ECONOMICS

Working Paper No. 24-09

! "#$%&' (%)*+ , ' - *. / '0 1.2#&")'0 +%&% 3 *e4'%5'6+")2'

!!!!!!!! / (01! / %)213!
4 156()75%8!&9! : &;&)0<&!=&2;<()!

$%& ' ()!*+,!*-* .!

,

!!!! " !# $%& ' ()!*+,!*-* .,! / (01! / %)213!

Carbon Policy with External Economies of Scale

Sean Strunk

Department of Economics

University of Colorado Boulder

October 25, 2024

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

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 negi437(imp0 J exrs:)-41

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

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

effects for a given industry[4]. These agglomeration effects offer a motiva-

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:

$$\frac{1}{{}_k} ln(x^k_{ij;t}) = {}^k_{i;t} + {}_{ij;t} + {}^k_{j;t} + {}^k_{ij;t} \tag{5}$$

where ^{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:

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

The first stage regression predicts the estimated price index:

$$ln(\hat{P}^h_{j;t}) = \sum_s {}_s 1_{s=h} \ ln(L_{j;t}) + \tilde{}_{j;t} + \tilde{}^h_t + \tilde{}^h_{j;t} \tag{6}$$

A set of instruments are constructed by interacting $L_{j;t}$, 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 .

$$ln(x^h_{j;t}) = (1 - \quad)ln(\hat{P}^h_{j;t}) + \quad_{j;t} + \quad_{h;t} + \quad^h_{j;t} \tag{7}$$

Where 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 = is smaller than the OLS estimate of = 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, L_j.

The definition for instrumented sector size is given as:

$$\hat{D}^h_i \equiv exp(\hat{\quad}^h_{i;t})L_i \tag{8}$$

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

$$L^k_i \equiv \frac{\sum_j X^k_{ij}}{\sum}$$

4.1.3 Estimation

To estimate the scale parameter I use data from third revision of the INSTAD database[7]

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

$^{+}$ $p < 0{:}10$, $p < 0{:}05$, $p < 0{:}01$, $p < 0{:}001$

pollutants are roughly equivalent[13]. Table B.1 shows the mean difference of ^{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 $= 0:05$.

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 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

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:

$$ln(\frac{CO2^k_{it}}{Output^k_{it}}) = \quad ln(EES^k_{it}) + \; {}_k + \; {}_i + \; {}_t + \; {}^k_{it} \tag{13}$$

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

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

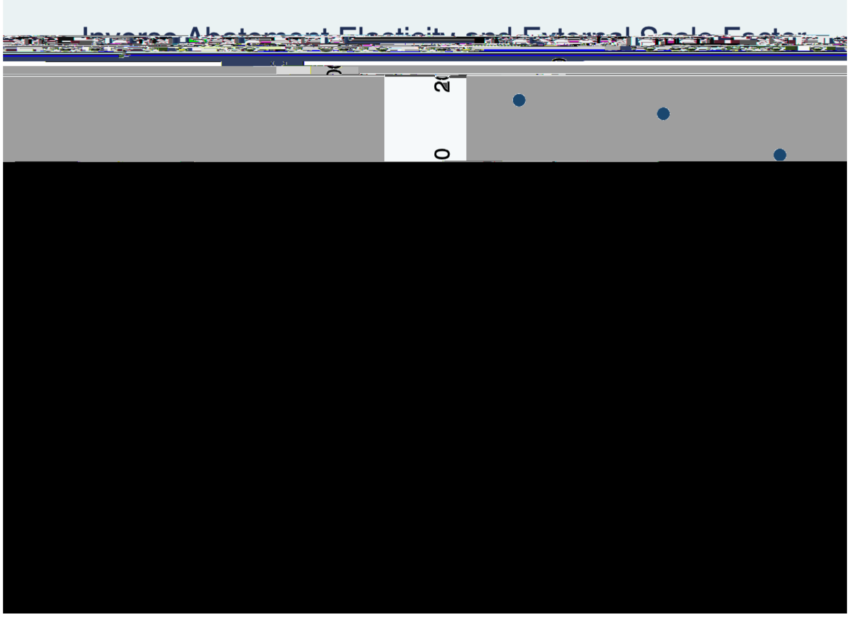
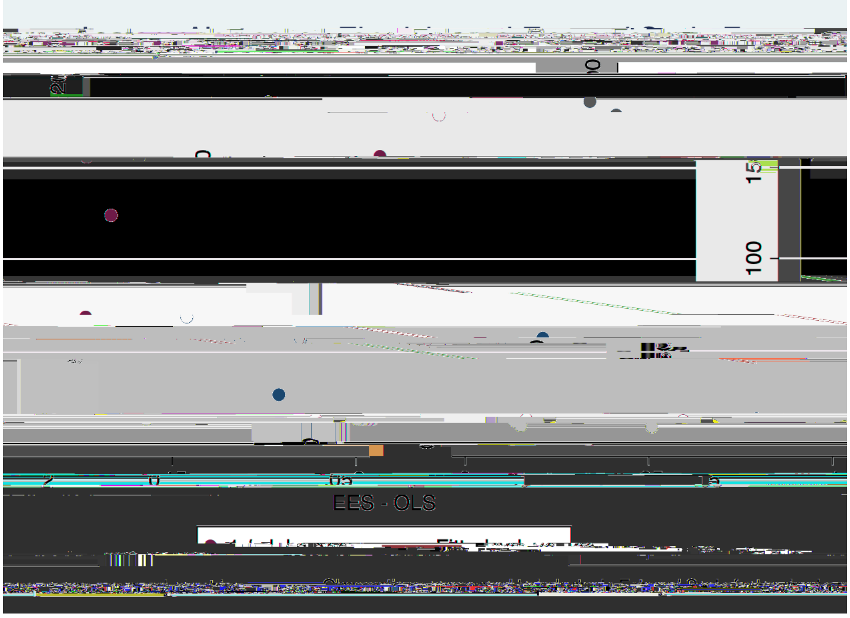


Figure 2: OLS



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.

References

[Aiginger u. Rodrik 2020] Aiginger, Karl ; Rodrik, Dani: Rebirth of industrial policy and an agenda for the twenty-first century. In: *Journal of industry, competition and trade* 20 (2020), S. 189–207

[Bagwell u. a. 2021] Bagwell, Kyle ; Staiger, Robert W. ; Yurukoglu, Ali: Quantitative analysis of multiparty tariff negotiations. In: *Econometrica* 89 (2021), Nr. 4, S. 1595–1631

[Bartelme u. a. 2024] Bartelme, Dominick G. ; Costinot, Arnaud ; Donaldson, Dave ; Rodriguez-Clare, Andres: The textbook case for industrial policy: Theory meets data / National Bureau of Economic Research. 2024. – Forschungsbericht

[Böhringer u. a. 2010] Böhringer, Christoph ; Fischer, Carolyn ; Rosendahl, Knut E.: The global effects of subglobal climate policies. In: *The BE Journal of Economic Analysis & Policy* 10 (2010), Nr. 2

[Brunel u. Levinson 2024] Brunel, Claire ; Levinson, Arik: Carbon Tariffs 101 / National Bureau of Economic Research. 2024. – Forschungsbericht

[Caliendo u. Parro 2015] Caliendo, Lorenzo ; Parro, Fernando: Estimates of the Trade and Welfare Effects of NAFTA. In: *The Review of Economic Studies* 82 (2015), Nr. 1, S. 1–44

[Chipman 1970] Chipman, John S.: External economies of scale and competitive equilibrium. In: *The Quarterly Journal of Economics* 84 (1970), Nr. 3, S. 347–385

[Conte u. a. 2021] Conte, Bruno ; Desmet, Klaus ; Nagy, Dávid K. ; Rossi-Hansberg, Esteban: Local sectoral specialization in a warming world. In: *Journal of Economic Geography* 21 (2021), Nr. 4, S. 493–530

[Copeland u. Taylor 2004] Copeland, Brian R. ; Taylor, M S.: Trade, growth, and the environment. In: *Journal of Economic literature* 42 (2004), Nr. 1, S. 7–71

[Costinot u.a. 2012] Costinot, Arnaud ; Donaldson, Dave ; Komunjer, Ivana: What goods do countries trade? A quantitative exploration of Ricardo's ideas. In: *The Review of economic studies* 79 (2012), Nr. 2, S. 581–608

[Cruz u. Rossi-Hansberg 2021] Cruz, José-Luis ; Rossi-Hansberg, Es-

[Naudé 2011] Naudé, Wim: Climate change and industrial policy. In: *Sustainability* 3 (2011), Nr. 7, S. 1003–1021

[Nordhaus 2015] Nordhaus, William: Climate clubs: Overcoming free-riding in international climate policy. In: *American Economic Review* 105 (2015), Nr. 4, S. 1339–1370

[Pigou 2017] Pigou, Arthur: *The economics of welfare*. Routledge, 2017

[Rodrik 2008] Rodrik, Dani: *Normalizing industrial policy*. Bd. 3. International Bank for Reconstruction and Development / The World Bank, 2008

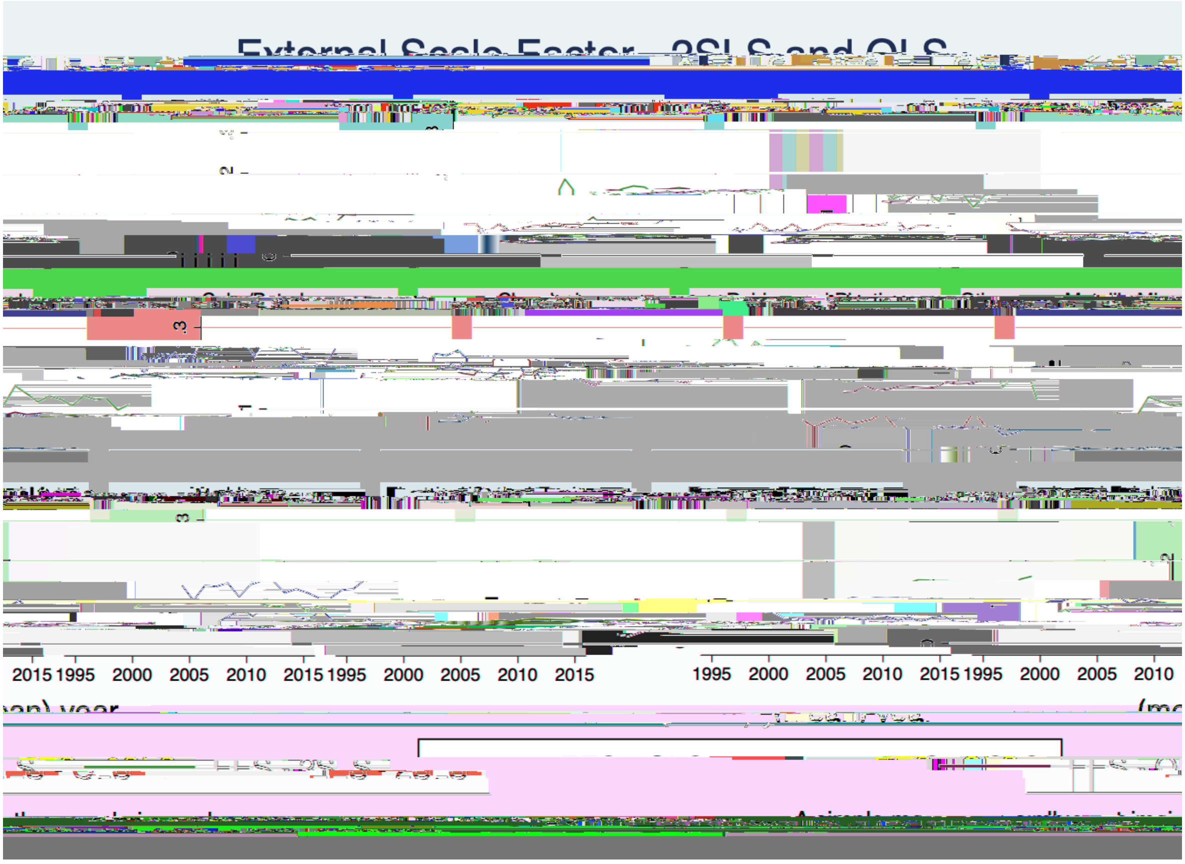
[Shapiro 2016] Shapiro, Joseph S.: Trade costs, CO2, and the environment. In: *American Economic Journal: Economic Policy* 8 (2016), Nr. 4, S. 220–254

[Shapiro 2022]

Appendices

A External Scale Factor

A.1 EES by Industry



A.2 2SLS Country - Industry Variation

A.3 OLS Country - Industry Variation

Table 5: ^{k} Sensitivity

Pollutant	Mean Ratio
CO: = 0:03	2.32
CO: = 0:05	2.27
CO: = 0:1	3.19
NOX: = 0:03	2.73
NOX: = 0:05	2.64
NOX: = 0:1	3.64
SOX: = 0:03	1.73
SOX: = 0:05	1.82
SOX: = 0:1	2.67
VOC: = 0:03	1.07
VOC: = 0:05	1.15
VOC: = 0:1	1.75

B Abatement Elasticity

B.1 Comparison to Shaprio and Walker (2018)