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Carbon pricing and local air pollution in California

Climate Policy Initiative

Andrew Hobbs
Kath Rowley

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Contact	Andrew Hobbs, San Francisco Office andrew.hobbs@cpisf.org

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Executive Summary

California's greenhouse gas (GHG) cap and trade scheme is scheduled to begin operation in 2013. The scheme will cap GHG emissions, helping reduce California's contribution to climate change. In addition, the scheme aims to deliver public health benefits by reducing local air pollution. Some environmental justice groups have questioned the scheme's ability to deliver meaningful air pollution reductions where they will have the most positive public health impact — in poor urban communities — and the associated legal challenges have delayed the scheme's implementation.[1] While the specific challenges have been resolved, concerns about the scheme's impact on air pollution remain.[2]

This paper therefore examines two key questions:

1. Has greenhouse gas (GHG) abatement due to cap and trade been associated with local air pollution (LAP) reductions?
2. How have reductions in GHGs and local air pollution been distributed?

To answer the first question, we examine the range of abatement actions California facilities are likely to take in response to a carbon price and how these actions affect local air pollution emissions. We also assess how local air pollution levels have changed in the European Union (EU) since its GHG cap and trade scheme commenced in 2005.

For the second question, we focus on GHG and air pollution around oil refineries. Many Californian refineries are located in poor urban communities, so pollutant reductions there could deliver significant public health benefits.

Key Findings:

Cap and trade is likely to deliver air quality improvements in California.

- **Actions that reduce GHG emissions also reduce local air pollution.** Carbon pricing incentivizes industrial facilities to be more energy efficient, reduce waste, and switch to cleaner fuels; our analysis shows that given existing policy, these actions reduce local air pollution emissions too. Where facilities reduce waste by installing new cogeneration capacity, local air pollution regulations apply directly to protect air quality.
- **In the EU, cap and trade appears to have cut both GHG and local air pollution emissions.** While many GHG and local air pollution policies operate together, our analysis suggests that as carbon prices rise, GHG and local air pollution emissions fall.

Cap and trade is likely to improve air quality in poor urban communities where oil refineries are located.

- **As California's oil refineries become more energy efficient, their local air pollution emissions will fall.** Increased efficiency means less combustion of fossil fuels, and hence fewer emissions.
- **EU oil refineries have achieved above-average cuts in their air pollution emissions.** California refineries have more limited fuel switching potential than EU refineries, so may see reductions closer to the average. Nevertheless, urban communities surrounding refineries should see air quality benefits.

1 See Goldsmith, H.E.H., 2011. Assn. of Irritated Residents, et al v. California Air Resources Board

2 For example, in March 2012, several environmental justice groups filed a suit claiming the program's use of offsets would shift potential air pollution benefits out of the state in violation of the civil rights act. See http://ggucuel.org/new-ab-32-lawsuit-challenges-use-of-offsets

Policy Implications:

Good coordination between California's cap and trade and air quality regulators can help maximize the local air pollution reductions flowing from GHG abatement efforts. To that end, regulators should focus on:

- **Preventing increases in local air pollution** by ensuring that where facilities expand or establish cogeneration, existing review processes are used to maintain local air quality.[3]
- **Using industrial audits to identify synergies and tensions between GHG and local air pollution abatement.** Facilities are already required to complete an audit to identify their GHG abatement options and potential impacts on local air pollution.
  - » This will help regulators identify abatement options that will maximize GHG and air quality benefits, and remove unnecessary regulatory barriers to them. Similarly, it would help regulators identify where existing air quality controls need to be adjusted to better protect air quality.
  - » Where abatement options are not cost effective on the basis of current carbon prices, but would deliver particularly strong air quality benefits, regulators may consider providing additional incentives.

3 Specifically, facility expansions require a New Source Review process under the Clean Air Act.

1. Introduction

The primary goal of a greenhouse gas (GHG) cap and trade program is to reduce emissions of pollutants that contribute to global climate change. From a climate perspective, the location of emissions is immaterial, as the extent of climate change is a function of global GHG emissions, regardless of location.[4] However, policymakers often identify additional goals to be achieved alongside GHG reductions, which must also be taken into account in assessing policy effectiveness.

In California, Assembly Bill 32 (AB32) set a statewide target of a return to 1990 GHG emission levels by 2020. While the bill did not specifically require that cap and trade be used to achieve this goal, it was part of the policy portfolio selected by the California Air Resources Board (CARB). AB32 specifically stipulates greenhouse gas regulations should be designed to complement air quality controls, prevent any increase in local air pollution emissions, and maximize additional environmental and economic benefits.[5] For this reason, the policy's impact on local air pollution (LAP) emissions[6] will be an important measure of its overall success.

During CARB's development of regulations implementing AB32, observers questioned the effectiveness of cap and trade as a mechanism for meeting the policy's public health objectives. Specifically, environmental justice advocates argued that the flexibility afforded by cap and trade may lead to increased concentration of local air pollution in poor and minority communities. Legal challenges were presented on this basis, and while these have been settled, the issue remains an important concern, and therefore warrants analysis.

This report explores the impact of cap and trade policy on GHG and local air pollution emissions for industrial facilities. Specifically, it seeks to answer two questions:

1. Has GHG abatement due to cap and trade been associated with local air pollution reductions?
2. How have reductions in GHGs and local air pollution been distributed?

The largest existing GHG cap and trade program is in the European Union (EU). While the EU did not specifically seek to maximize public health benefits from its cap and trade program, its system is similar to California's in many ways. On this basis, we explore EU data and discuss the implications of our findings in the California context.

Cap and trade's impact on local air pollution depends on which abatement strategies regulated facilities select and how those strategies interact with other regulations — most importantly, air quality controls. While large stationary emissions sources in California use a wide range of fuels, produce different products, and face different regulations, their GHG emissions are largely due to the combustion of fuel for heat or energy. As a result, the set of broad GHG abatement strategies is fairly limited: Facilities can change process fuels, increase efficiency, reduce production, and/or buy allowances. We examine each of these strategies in turn, and identify how each is likely to affect local air pollution.

In California, oil refineries are major sources of local air pollution in poor and minority communities, and are therefore a focus for environmental justice efforts. In Pastor's (2011) ranking of California emitters with a disparate impact on poor and minority communities, refineries occupy eight of the top ten positions. For this reason, this analysis pays special attention to refinery abatement strategies and how GHG and local air pollution emissions from refineries changed in the EU.

Rigorous quantitative analysis of cap and trade's impact on local air pollution is challenging, particularly because cap and trade operates simultaneously with air quality controls. Our analysis of the EU experience relies on the relationship between changes in emissions patterns and carbon prices to derive its results. We cannot be sure we have excluded all the effects of EU air quality controls; as a result, our empirical results ought to be taken as indicative rather than conclusive. More data — which will become available over time as policy experience accumulates — would help confirm this relationship and explore it in greater detail.

This paper proceeds in four parts. First, it summarizes the most important local air pollution and GHG emission policies in the United States and EU. Second, it identifies the types of GHG abatement options available to

4 Jacobsen (2010) finds that carbon dioxide domes formed over urban areas may increase ozone formation and particulate matter. As a result, some argue carbon dioxide should be viewed as a local air pollutant as well as a greenhouse gas.

5 Part 4 § 38562 and Part 5 § 38570 of Assembly Bill 32 http://www.arb.ca.gov/regact/2010/capandtrade10/capv1appb.pdf

6 Specifically, we look at emissions of sulfur dioxide, nitrogen oxides, ozone, and particulate matter.

industrial facilities generally and oil refineries in particular; it then examines their relative impacts on local air pollutant emissions. Third, the paper analyzes the relationship between carbon pricing and local air pollution emissions in the EU; again, for industrial facilities generally and refineries in particular. Finally, we discuss the implications for California and how regulators can help ensure California's cap and trade scheme achieves its goal to improve air quality.

2. Greenhouse Gas and Local Air Pollutant Policy in the EU and U.S.

Regulatory systems in the EU and U.S. are similar in a number of key respects. Both jurisdictions have a regionally administered regulatory framework based on achieving air quality targets, and California and the EU have both implemented cap and trade systems for GHGs.

2.1 Cap and Trade Programs

The EU cap and trade program covers all 27 EU member states, plus Iceland, Norway, and Liechtenstein. Its pilot phase began in 2005 and lasted three years, followed by a second phase from 2008 - 2012; the third phase begins in 2013. California's system is similarly designed: Its first phase will include 2013 and 2014, and future phases will be three years long. The EU and California emissions trading programs seek to reduce GHG emissions at a similar rate, but differ in terms of coverage, allocation system, and offsets. Most significantly, California's system in its second phase will include transportation fuels in the cap; the EU relies on a separate suite of regulations for tackling emissions in the transport sector.

Differences in the California and EU allocation systems may eventually lead to differences in program outcomes, but these differences are less pronounced in the early phases of each program. In the EU Emissions Trading Scheme (ETS), allocation is regulated at the EU level and administered by each country's national government. The EU ETS provides free allocation based on leakage risk: Facilities whose increased production costs might lead production to shift outside the EU (commonly referred to as carbon leakage) are provided free allowances up to an ambitious sectoral benchmark based on the performance of the top 10 percent of installations in the EU. Since electricity generation is essentially impossible to move outside the ETS jurisdiction, power sector allowances are fully auctioned (with a few transitional exceptions to be phased out by 2020). California also provides free allocation based on leakage risk; however California also provides a form of free allocation to the power sector to protect electricity ratepayers.

2.2 Local Air Pollutant Policy

Local air pollution regulations co-exist with climate policies; their interaction determines the impacts of climate policy on local air pollution emissions. In both the EU and U.S., local jurisdictions require emitters to comply with regionally-administered air quality limit values. Areas where limits are exceeded are subject to more stringent facility-level regulation, and installing new pollution sources requires additional permitting. Table 1 compares air quality limit values for the EU and U.S. In general, the EU imposes stricter limits, but allows them to be exceeded more often. California has an additional set of more stringent standards, although several air basins in California are consistently in non-compliance with a subset of both federal and state standards.

Additional EU Policies

The EU has implemented a number of policies to regulate emissions at the national and facility level. The National Emissions Ceiling Directive sets limits for each EU member state, while the Large Combustion Plants (LCP) Directive sets thermal-input-linked emissions limits by fuel for all combustion facilities with over 50 megawatts of thermal input. The LCP standards were set in 2001, however facilities were not required to comply with those standards until 2008, which

Table 1: EU and U.S. air quality limits, and number of annual violations permitted

POLLUTANT	EU ($\mu g/m^3$)	U.S. ($\mu g/m^3$)
Sulfur Dioxide (24 hr)	125; 3 violations	365; 1 violation
Nitrogen Dioxide (annual mean)	40	100
PM 10 (24 hr)	50; 35 violations	150; 1 violation
Ozone (8 hr mean, 2 year average)	120[1]	160[2]
Carbon monoxide	10,000	10,000; 1 violation

[1] Not allowed to be exceeded on more than 25 days per year averaged over three years
[2] Value is for average of fourth highest daily maximum

coincided with the beginning of the EU ETS. This presents particular challenges in distinguishing the impacts of the two policies.

An additional policy relevant to the refinery sector was Auto Oil II, which increased the stringency of transportation fuel standards. This required refiners to increase hydrotreatment of fuels to reduce nitrogen dioxide emissions from their eventual combustion. While this does not necessarily have direct impacts on local air pollution emissions at refineries, it increases the energy intensity of refining and hence increases refinery GHG emissions. This may have offset facility-level reductions resulting from the LCP Directive and EU ETS.

These simultaneous policies make it challenging to separate impacts of the EU ETS and other air pollution policies. We use carbon prices to help isolate the impact of the ETS: Carbon prices are a measure of the stringency of the EU ETS and changes in carbon prices are independent of local air pollution policy. However, carbon prices are correlated with the enforcement of the LCP Directive, so our results may to some extent still reflect the impact of the LCP Directive. We focus on the relationship between *changes* in carbon prices and changes in local air pollution emissions to improve our estimate of the ETS impact; this also allows for the nonlinear relationship between carbon prices and emissions levels.

3. Greenhouse Gas Abatement Strategies: Feasibility and Local Air Pollution Impacts

In general, carbon prices increase the relative cost of operating a high emissions facility. That is, within an industry, a significant carbon price will put an energy-intensive facility at a disadvantage relative to an energy-efficient one. This means carbon prices will lead facilities to reduce energy intensity and emissions, particularly when they are more energy intensive than their competitors. It also means they may have to increase prices of energy-intensive goods, which will lead to less demand and hence reduced production over time. This section analyzes these effects at the facility level and for the refinery sector in particular. We show that of the various abatement strategies, cogeneration is the only one that could increase local air pollution, and existing air quality regulation ought to prevent this in already dirty air basins.

At the facility level, there are two basic ways to reduce GHG emissions:

1. Reduce the quantity of fuel burned. To burn less fuel, a facility can either reduce production, switch from heavier to lighter crude oil ("feedstock switching"), or improve its energy efficiency.
2. Reduce emissions per unit of fuel consumed (emissions intensity). To reduce emissions intensity, a facility can either install technologies that capture some or all of the emissions, capture and make use of previously wasted energy, or switch to fuels whose combustion generates fewer GHG emissions.

A cap and trade system does not *require* all facilities to reduce emissions. Instead, each facility finds its own cost-effective level of abatement action, and buys permits (or retains freely-allocated permits) for the remainder of its emissions.

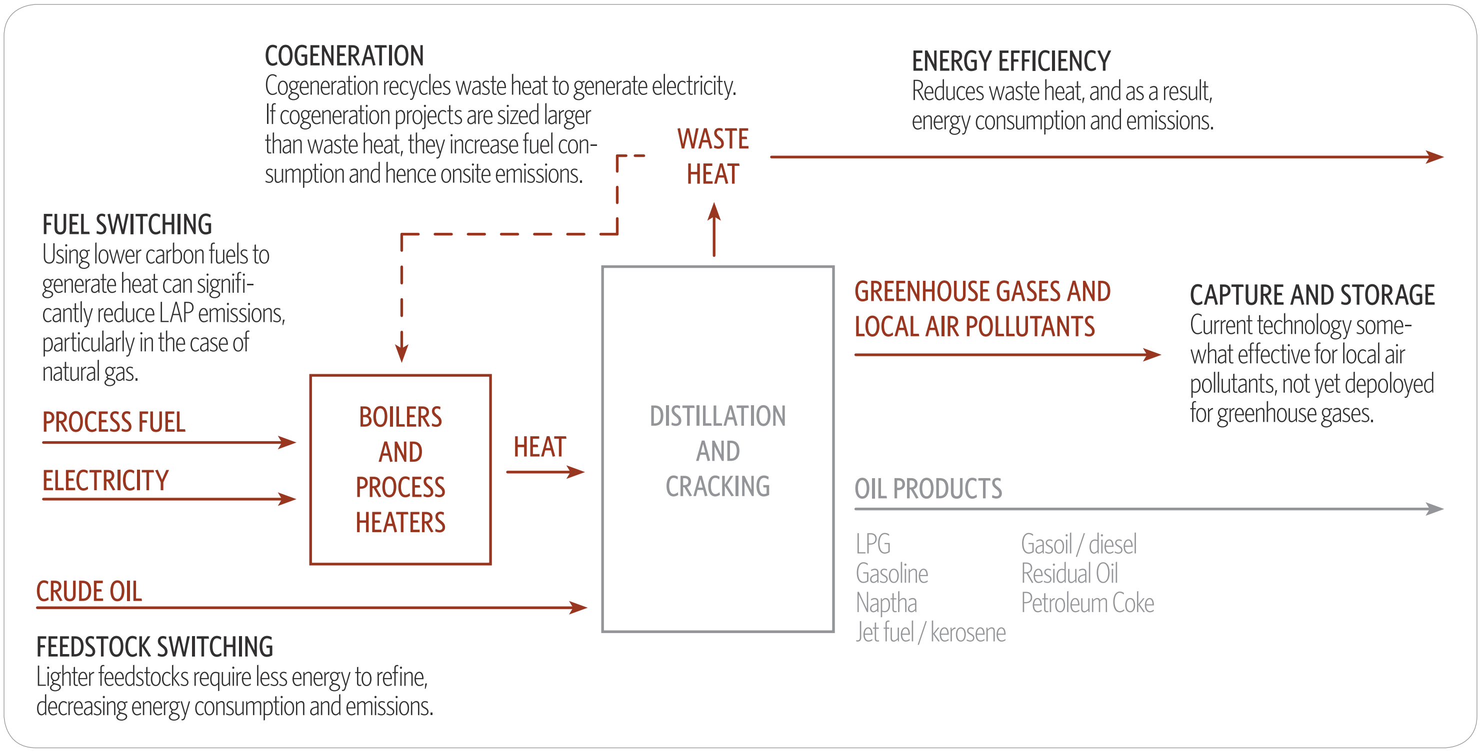
Comparing the costs of rival compliance strategies is complex. Abatement measures require capital investment and are costly to reverse, so short- and long-term expectations influence the decision. Facility managers know the relative costs of various abatement measures may change, so they are willing to pay a premium for strategies that preserve their ability to adapt to changing conditions. Expectations of technological change, fossil-fuel price volatility, and demand uncertainty all increase this premium. For this reason, in some cases, strategies that do not require capital investment may be preferred because they are associated with less risk, even when their expected net present value to the facility is lower.

Table 2 categorizes abatement strategies by type and capital investment needs. Typically, energy efficiency, cogeneration, and carbon capture and storage require

Table 2: Capital Investment Requirements for Abatement Strategies

REQUIRES CAPITAL INVESTMENT?	REDUCE ENERGY CONSUMPTION	REDUCE GHG EMISSIONS INTENSITY
No	Reduced production Feedstock switching (refineries)	Fuel switching
Yes	Energy efficiency	Cogeneration Carbon capture and storage

Figure 1: Abatement strategies for an oil refinery



capital investment; reduced production and fuel switching do not.[7]

The distinction between energy efficiency and cogeneration deserves additional explanation, as both strategies reduce emissions intensity by eliminating waste. We separate the two because, with the exception of cogeneration, energy efficiency measures can unambiguously be expected to reduce energy consumption. Cogeneration, on the other hand, means making better use of the energy consumed rather than reducing on-site energy consumption. This distinction is important in this case, as the implications for local air pollution are distinct.

In general, all the abatement strategies identified, except cogeneration and carbon capture and storage, would be expected to reduce the facility's local air pollution emissions. Carbon capture and storage technology has not yet been deployed at significant scale, so its impact on local air pollution is unclear. For this reason, this report does not discuss it further. Cogeneration can increase local air pollution if the cogeneration plant increases the facility's thermal input, unless local air pollution regulations prevent it.

Focusing now on refineries, we know that carbon prices will have a larger impact on the more energy intensive refineries. However, in general, trends in crude oil production favor these more complex, energy-intensive refineries, and carbon prices are unlikely to outweigh this effect.[8]

Figure 1 illustrates where abatement opportunities arise for a typical oil refinery. Reduced production is not specifically illustrated; obviously, reduced production at the refinery reduces energy use and associated emissions. As Figure 1 indicates, only process fuel switching affects what is burned at the facility — all other strategies simply affect the quantity of energy required.

The following sections will briefly discuss the feasibility of each of the facility-level abatement strategies identified for the refinery sector, and their impact on local air pollution. The discussion is summarized in Table 3 at the end.

7 Note this general relationship does not hold in all cases: for example, switching from a coal boiler to a natural gas turbine would involve substantial capital investment; some energy efficiency improvements involve operational change rather than investment.

8 Reinaud (2008) finds that a twenty euro per ton carbon price adds only a dollar a barrel to refinery costs — while this is not trivial, it is likely outweighed by expected changes in light and heavy crude prices.

3.1 Reduced Energy Consumption

Reduced energy consumption in a facility means reduced fossil-fuel combustion and hence fewer local air pollution emissions. In general, reductions can be expected to occur in a one to one fashion: A 10 percent reduction in fuel combustion yields a 10 percent reduction in both GHG and local air pollution emissions. If savings are spread across different fuels, fuel switching may also occur. This is discussed in section 3.2.

Feasibility: Reduced Production

At an industry-wide level, production will fall when increases in the ultimate consumer prices lead to lower demand. The degree to which this occurs depends on how sensitive consumers are to price changes. However, when reductions occur they may not be split evenly across facilities: The highest cost facilities will be the first to cut production. Since carbon prices increase the cost of operating a more energy-intensive facility, they should lead to greater reductions for the most energy-intensive producers.

Metcalf (2008) estimates that a $15 carbon price would increase pump prices for gas by 13 cents per gallon, resulting in a 1-3 percent reduction in demand.[9] Thus, we can expect some reduction in production, and this effect will increase as carbon prices rise.

At the same time, other factors such as increased global oil demand, reduced production, and changes in feedstock quality are affecting consumer prices and the relative competitiveness of different facilities. These larger forces are likely to outweigh the effect of the carbon price on the facility's production levels.

Feasibility: Feedstock Switching

Feedstock switching is a refinery-specific abatement strategy. "Feedstock" refers to the crude oil that the refinery processes. A refinery's function is to separate crude oil, which consists of long hydrocarbon chains, into shorter, more useful hydrocarbons, such as gasoline, diesel, and jet fuel. Heavy crude oil contains more carbon, meaning it produces lower quantities of useful products, particularly in simpler, less energy-intensive refinery configurations. For this reason, more processing is required to extract maximum value from heavier crude. This means that a refinery's choice of feedstock affects its energy intensity: Heavier feedstock means more energy consumption.

Carbon prices increase the cost of energy and discourage refining heavy crude oil. That said, California's refineries already refine relatively light crude oil due to other regulations, and if California stops refining heavy crude oil, the feedstock may simply be processed elsewhere. However, many broader global market factors affect the splits between light and heavy crude oil. These factors are likely to outweigh carbon prices in determining feedstock choices.

Feasibility: Energy Efficiency

Energy efficiency is often identified as among the lowest cost strategies for reducing society's total GHG emissions. It is therefore likely to feature in facilities' response to carbon pricing. As noted above, significant energy efficiency upgrades often require significant capital investment, so facilities may prioritize low-capital efficiency improvements in the near term and defer major energy efficiency improvements even when they appear cost effective.

Refining is an energy-intensive industry: Facilities operate in a competitive environment where a relatively small efficiency advantage can give a refinery an edge. Estimates indicate the U.S. refinery industry as a whole could cost-effectively reduce energy consumption by 13 percent by 2020 (McKinsey and Company, 2007), even without a carbon price. Further, implementing new technologies that are already available could reduce the industry's energy consumption by 26 percent (Energetics Incorporated, 2006). However, identifying energy efficiency opportunities can be a complex process and implementation may require reducing or suspending production for a period of time, so this potential may take some years to realize on its own. A carbon price should accelerate this process.

3.2 Reduced Emissions Intensity

Facilities can reduce emissions intensity either by switching to lower-carbon fuel (e.g. from coal and oil to gas and renewable energy), or by installing cogeneration. Lower carbon fuels are also lower in local air pollutant emissions, so fuel switching will reduce local air pollution.

9 Existing research indicates the elasticity of demand for gasoline around -.34 in the short run and -.84 on the long run (Brons. et al, 2008). Thus, assuming a $4/gallon baseline, a 13 cent (3.25%) increase would be expected to lead to a reduction in demand in the range of 1.1-2.7% (short vs. long run).

Table 3: Abatement strategies and their impact on refinery local air pollution (LAP) emissions

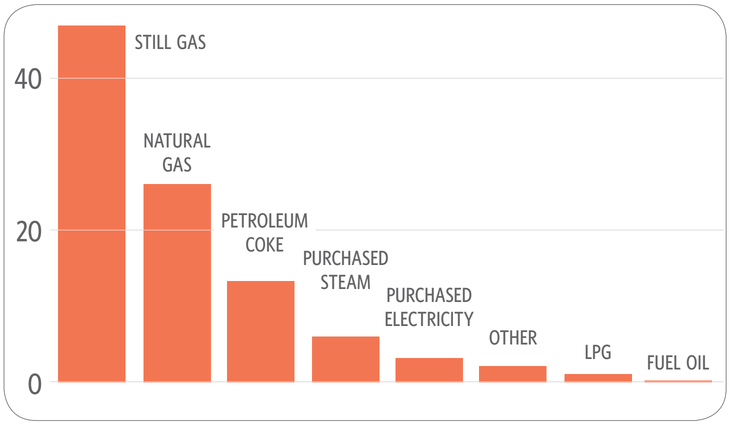
ABATEMENT STRATEGY		IMPACT ON LAP	LIKELY SIZE OF EFFECT
Reduce energy consumption	Reduce production	Reduce	Small; small relative to other drivers
	Feedstock switching	Reduce	Limited scope; small relative to other drivers
	Energy efficiency	Reduce	Significant scope, especially over time
Reduce emission intensity	Fuel switching	Reduce	Limited scope in California
	Cogeneration	None or increase	Some scope; increases subject to LAP controls

Cogeneration does not reduce emissions of the facility's local air pollution and GHGs, though it does increase the productivity of those emissions (and by displacing other energy generation, it reduces emissions elsewhere).

Switching from higher-carbon to lower-carbon fuels often leads to a more than proportional reduction in local air pollutant emissions. Individual fuels vary, but the difference between air pollution emissions from clean and dirty fuels is generally greater than the difference in GHG emissions. For example, based on U.S. power sector averages, switching from 100 percent coal to an 80/20 coal/gas mix would reduce carbon dioxide emissions by 10 percent, would reduce SO_2 emissions by almost 20 percent, and NO_X emissons by about 14 percent.

Cogeneration impacts depend on the size of the project. If the project is sized to electricity demand, it will fully satisfy the facility's electricity consumption. If the project is sized to scale, the facility manager will optimize to electricity market conditions, and sell any excess to the grid. If the project is sized to heat demand, it maximizes use of the existing waste heat, and will have no impact on the facility's GHG or local air pollution emissions. Sizing to demand or scale may introduce a larger unit, increasing the facility's energy consumption and associated emissions.

Figure 2: Process fuel mix in PADD V (West Coast) refineries



In this case, local air pollution permitting requirements play a key role: They can and should prevent an overall increase in facility local air pollution emissions in areas where air quality is a particular concern. The facility manager's choice will be dictated by regulatory and market conditions, discussed in the feasibility section below.

Feasibility: Fuel Switching

Fuel switching is an attractive mitigation option when lower-emissions fuels are available and the difference in fuel price is less than the difference in the cost of required GHG emissions permits. The ability to switch fuels may be constrained by technology (some technologies require a particular fuel or mix of fuels to operate) or by access (natural gas is more readily available close to pipelines while petroleum products will be less expensive near or at refineries).

Refineries produce a large fraction of their own fuel: The refining process splits crude oil into petroleum coke, fuel oil, diesel, gasoline, refinery gas, jet fuel, and liquefied petroleum gas, among other things. In theory, any of these products could be used to generate the refinery's energy. In practice, refineries use primarily natural gas, refinery gas, liquefied petroleum gas, fuel oil, and in some cases petroleum coke. Diesel, gasoline, and jet fuel are much more valuable to the refiner if sold as products. Petroleum coke has an emissions profile similar to coal; it produces relatively high levels of GHG and local air pollution emissions, so switching to other fuels would be beneficial. However, switching from coke to other fuels is costly. While "marketable" petroleum coke can be sold, "catalyst" petroleum coke is generally used only at the refinery site for fuel. As a result, petroleum coke is essentially a negative-cost fuel for refineries; if they chose not to burn it they have to pay to dispose of it. Switching to cleaner fuels will therefore only be cost-effective at high carbon prices.

In the EU, refinery operators reported switching from fuel oil to natural gas when sulfur dioxide emissions ceilings drew close (Lacombe, 2008). However, as shown in Figure 2, refineries in the U.S., particularly in California, use almost no fuel oil as it is. Natural gas and still gas are both relatively clean fuels, meaning the abatement potential for GHG and local air pollution from fuel switching is limited.

Feasibility: Cogeneration

Cogeneration is a cost-effective, appealing GHG abatement option. In fact, some California facilities have already implemented it. Cogeneration plants can be sized in a variety of ways, and if permitted by local air pollution control authorities, large cogeneration plants could potentially increase local emissions at the site. However, in dirty air basins, such projects would have to undergo a new source performance review, where local air pollution issues are specifically considered and controlled.

For oil refineries, a cogeneration plant built to capture all existing useable waste heat will generally meet the facility's electricity needs and sell leftover electricity to the grid, and have no impact on emissions. A larger plant would increase energy consumption and emissions; as before, it would be subject to a new source performance review. Cogeneration has been implemented at refineries in both California and the EU, and carbon prices will make it more attractive. While cogeneration is unlikely to reduce local air pollution emissions at the facility site, it will reduce aggregate power demand, and hence reduce local air pollution emissions from other facilities in the power sector.

3.3 Policy Interactions

As the previous section shows, industrial facilities generally, and refineries in particular, have a range of feasible GHG abatement strategies which would also reduce local air pollution emissions. Whether these reductions are realized, however, depends on how local air quality regulations operate. For this reason, this section examines the interaction between GHG abatement strategies and local air quality regulations.

Local air quality regulators are faced with two closely related goals: to prevent increases of local air pollution emissions, and to maximize reductions in local air pollution emissions. As a result, air quality regulations are complex. A facility's various components may be subject to an array of requirements, some linked to thermal input, some capping emissions based on what is considered technologically feasible, and some mandating the use of a particular technology. Further, new additions to a facility are often subject to different requirements than existing structures.

Table 4 shows how the facility-level responses to carbon pricing discussed above interact with air quality policies, and draws out the air pollution outcomes. It groups air quality regulations in three groups: (1) thermal input linked limits, (2) emissions caps, and (3) technology requirements. These interact with GHG abatement in a different way: Thermal input linked limits and technology requirements ensure local air pollution emissions are reduced when a facility increases its efficiency or reduces production; emissions caps prevent increases in emissions if a facility expands production.

Table 4: Abatement strategies and their impact on local air pollution under different air quality controls

	Air Quality Regulation		
Abatement strategy	Thermal Input Linked Limit	Emissions Cap	Technology Requirement
Reduce Energy Consumption (energy efficiency, reduced production)	Ensures reduction	No clear change	Ensures Reduction
Reduce Emissions Intensity (fuel switching, CCS)	No clear change	No clear change	Ensures Reduction
Increase Energy Consumption (expansion, cogeneration)	Increase possible	Prevents Increase	Increase possible

This means air quality policies have varying advantages and disadvantages. While a thermal input linked limit captures local air pollution reductions when a facility reduces production, it leaves open the possibility that increased production will increase emissions. Emissions caps prevent such increases, but may not capture reductions below the cap. Technology requirements, which are perhaps the most common, ensure reductions from energy efficiency but again leave open the possibility that increased production or increased energy intensity (from heavier feedstocks, for example) may increase local air pollution.

Where GHG abatement leads to lower air pollution emissions, air quality regulators should be able to capture those benefits. Special attention is required where a facility plans to increase its energy consumption; in this case an emissions cap would guard against increased local air pollution emissions.

In some cases, local air pollution controls may increase GHG abatement costs without delivering any extra local air pollution benefit. For example, stringent air quality requirements for new additions to an existing facility could make energy efficiency upgrades that would reduce both local air pollution and GHG emissions more expensive and therefore less attractive. In this case, the facility's local air pollution controls may need to be adjusted to ensure policy provides incentives to minimize local air pollution emissions without discouraging GHG abatement.

4. Emissions trading and local air pollutants: the EU experience

Data from the EU ETS allows us to explore changes in emissions in a similar system, which informs our expectations for California. This section provides a brief analysis of the effect of carbon pricing on GHG and local air pollution emissions in the EU to date.

Emissions levels are influenced by a wide range of factors, including weather, economic conditions, fossil-fuel prices, and policy. We use a panel regression to isolate the impact of carbon prices on emissions levels. Specifically, we estimate the impact of changes in carbon prices on changes in emissions of local air pollution and greenhouse gases.

Our local air pollution data, and hence our regression, spans five nonconsecutive years: 2001, 2004, 2007, 2008 and 2009. We control for GDP, natural gas, coal, and crude oil prices. In the refinery model, we also control for 'crack spreads,' which represent the difference between sale prices and costs from a refinery perspective. Greater detail on the statistical analysis is provided in the appendix.

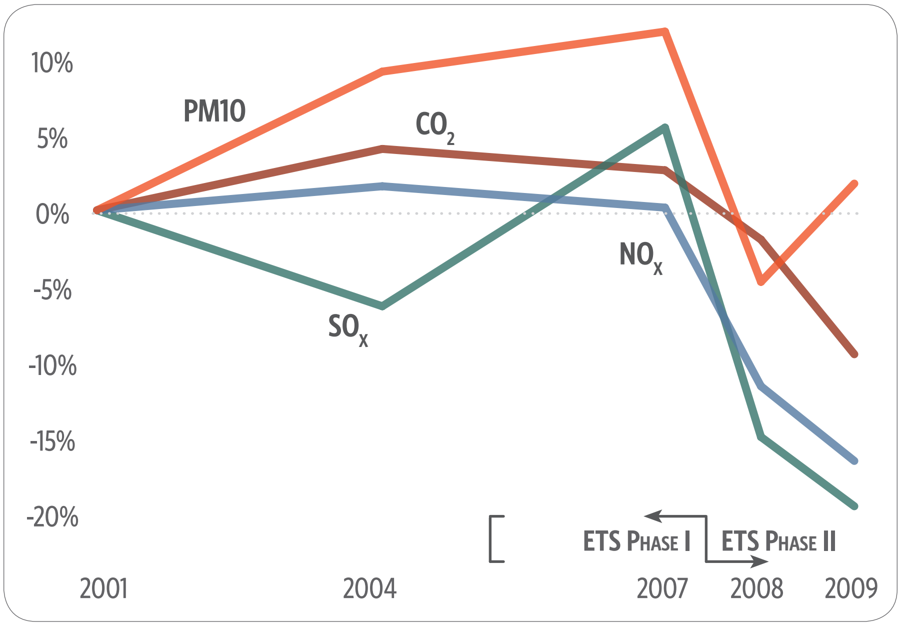
The primary limitation of this analysis is our inability to effectively control for changes in local air pollution policy, which occurred at the same time as the ETS. As discussed in section 2, the LCP Directive tightened local air pollution controls in 2001, but compliance was not required until 2008. We would therefore expect the LCP Directive to have led to a significant decrease in pollution as the ETS came into effect, and some of the effect we report for the carbon price may instead be due to the LCP Directive. However, our results remain qualitatively consistent if we include first phase prices, which start a year earlier in our dataset. Further, the effects are consistent with our analysis of abatement strategies in section 3. These factors give us greater confidence in the results reported here.

We use average annual carbon prices because these are the best available measure of the policy's stringency (or at least expected stringency) over the course of a year. We are estimating the percent impact of a 1 percent change in permit price on emissions levels. This is appropriate because abatement cost curves are likely not linear. It also means that our estimates are only accurate for prices relatively close to those observed under the EU ETS thus far; this is not problematic because price forecasts for the first years of California's scheme are in the same range as EU ETS prices in 2008-09.[10]

The results presented in the next sections focus on the second phase of the EU ETS, which began in 2008. During the first phase, prices plunged toward zero due to a combination of abatement and over-allocation in some jurisdictions. In the second phase, unlimited banking of permits has prevented this outcome. Nevertheless, the statistical models presented reach similar conclusions when the first phase is included.

10 See, for example: Synapse Energy Economics Inc, July 2008, Synapse 2008 CO_2 Price Forecasts (online at http://www.synapse-energy.com/Downloads/SynapsePaper.2008-07.0.2008-Carbon-Paper.A0020.pdf); Point Carbon, 7 August 2012, Carbon Market Monitor.

Figure 3: Change in emissions from the average industrial reporting facility from 2001 to 2009 (Percentage calculated from 2001 base year)



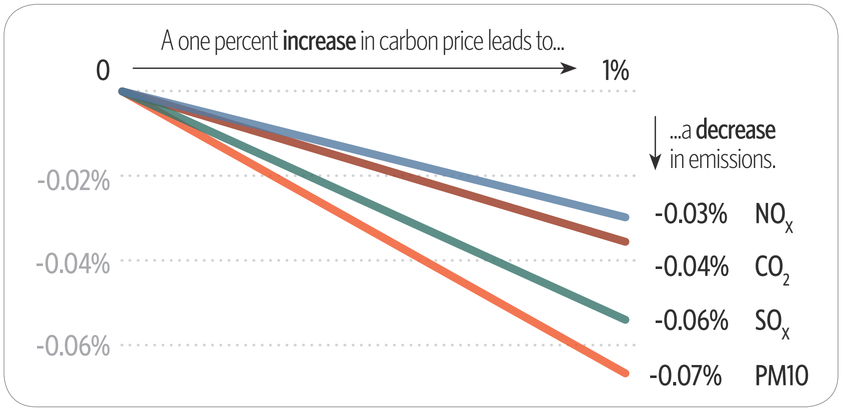
4.1 Emissions from industrial facilities

In 2008, there was a clear reduction in emissions of both local air pollutants and carbon dioxide. Relative to 2007, carbon dioxide levels fell 5 percent, sulfur dioxide fell 20 percent, nitrogen oxides fell 12 percent and particulate matter fell 17 percent for the average reporting facility.

As noted above, these reductions resulted from multiple simultaneous policy and economic drivers. Once we control for fossil-fuel prices and economic conditions, we see a small, statistically significant relationship between carbon prices and emissions of both LAPs and GHGs (Figure 4). This means higher carbon prices are associated with lower emissions, and that the relationship is very unlikely to be due to random chance. The result suggests the cap and trade policy is having its intended effect.

The change in sulfur dioxide and particulate matter emissions is larger than the change in carbon dioxide. This is consistent with some degree of fuel switching from coal and/or fuel oil to natural gas (as discussed in section 3.2).

Figure 4: The impact of carbon price on emissions at the average facility



4.2 Emissions from oil refineries

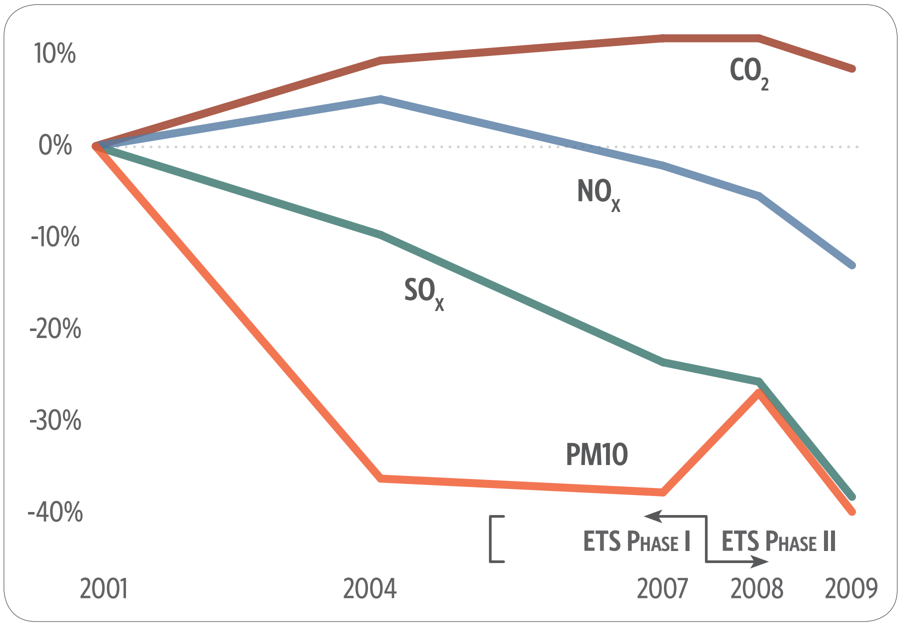
Emissions from oil refineries of all pollutants studied have decreased since the start of the EU ETS, though particulate matter spiked in 2008 (Figure 5). This spike may be due to the economic slowdown: We find a negative relationship between gross domestic product and particulate matter (that is, as GDP increases, particulate emissions decline). Once we control for economic conditions and fuel prices, we find a negative relationship between carbon prices and emissions of all pollutants; that is, as carbon prices go up, pollutant emissions go down (Figure 6). This relationship is statistically significant for all pollutants.

The relationship is strongest for particulate matter and sulfur dioxide. This is consistent with refineries switching from fuel oil to natural gas; as discussed previously, natural gas produces very little sulfur dioxide and particulate matter emissions. It is also consistent with Lacombe (2008), who found, based on a series of interviews with refinery operators in the EU, that some refinery operators switched from fuel oil to natural gas when nearing sulfur dioxide limits to comply with the LCP Directive. Lacombe also found many refinery operators had started factoring carbon prices into their plans and operations in Phase I of the ETS. Our regression analysis focuses on Phase II, so may underestimate the impact of the carbon price.

4.3 Distribution of Emissions Reductions

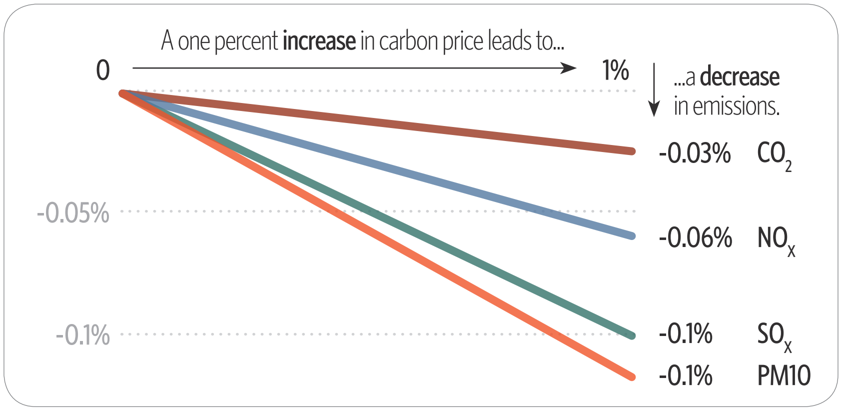
The EU experience suggests California's cap and trade program will reduce both GHG and local air pollution emissions in the average facility: That is, it will have a positive impact on air quality overall. However, absent much more detailed facility-level data, we cannot estimate the likely effect for specific facilities. Nevertheless, we can derive insights relevant to California's environmental justice concerns. Recall that, in California, refineries are the facilities of greatest public health concern. Two questions therefore arise: Are local air pollution emissions likely to increase at refineries; and if not, are refineries likely to see larger or smaller air quality improvements than the average?

Figure 5: Change in emissions from an average reporting refinery from 2001 to 2009 (Percentage calculated from 2001 base year)



As discussed in section 3, the only abatement strategy that could increase local air pollution emissions from a refinery is installation of a large cogeneration plant. This would require significant new works at the facility, triggering new source review requirements that would assess and specifically control air pollution emissions. If the refinery were located in a region of poor air quality, this permitting process is very likely to prevent any deterioration.

Figure 6: The impact of carbon price on emissions at the average oil refinery



The EU experience discussed above shows that cap and trade is associated with lower GHG and local air pollution emissions from refineries. While the change in GHG emissions was smaller for refineries than for the average facility (which perhaps reflects the effect of Auto Oil II), the change in local air pollution emissions was much stronger than average. For the same change in carbon price, we see a 50 percent stronger reduction in particulate matter and almost double the reduction in sulphur dioxide and nitrogen oxides (Figure 6).

This suggests air quality around refineries in the EU would have improved more than the average. It is not clear that this result would be fully replicated in California, as the particular facilities and industrial mix are different, and California refineries have less potential for fuel switching. Nevertheless, the result gives cause for cautious optimism.

5. Implications for California

Our analysis of abatement strategies, together with the EU experience, give us reason to expect that cap and trade would improve air quality in California. The most feasible GHG abatement strategies reduce local air pollution emissions. As EU carbon prices rose, air pollution emissions fell.

Further, air pollution emission reductions at EU refineries were more substantial than for the average facility. While California refineries have less scope to switch to cleaner fuels, if the general pattern holds, the environmental justice impacts of cap and trade in California could be positive, reducing air pollution emissions from refineries in poor urban communities.

Air quality regulators will be central to determining whether the potential air quality benefits of California's cap and trade program are realized. Implementation arrangements for cap and trade should help. The California Air Resources Board (CARB) has mandated that all facilities conduct an industrial audit for GHG abatement strategies.[11] This will identify the specific local air pollution benefits of each strategy at a facility level, which should help air quality regulators realize the benefits and/or prevent deterioration of air quality. It could also help regulators identify where existing air pollution controls unnecessarily increase the cost of GHG abatement. The industrial audit process therefore provides a promising pathway to help AB32 achieve its air quality objectives.

The facility audits may also help identify abatement actions which deliver strong GHG and local air pollution benefits, but which are not cost effective based on carbon prices expected in the near term. Where these opportunities arise in areas with poor air quality, there may be a case for financial incentives to encourage their uptake. CARB is currently considering options for using the revenue generated through emissions permit auctions; this might be an attractive option.

Overall, our analysis of abatement strategies and experience in the EU suggests that California's cap and trade program will have a positive impact on air quality and in turn public health. It is still early days: The EU will provide stronger lessons as more data becomes available. Further, as California's scheme unfolds, we can track changes in GHG and local air pollution emissions from refineries and other covered facilities. This will allow us to draw stronger conclusions on the complex relationship between greenhouse gas abatement and local air pollution.

11 State of California Air Resources Board, Executive Order R-11-004 (9 May 2011); California Code of Regulations Title 17 Division 3, Chapter 1 (10), Article 4 (9).

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Appendix: facilities, gases, refineries, and particles

A short story

1 Production and carbon prices

For the purpose of this analysis, we'll consider a simple cost minimization model where pollution is an input. We will be estimating the elasticity of demand for carbon emissions using a standard approach, but a bit of discussion is useful in thinking about the interpretation of these elasticities. Suppose an industrial facility's production function is $y = f(x)$, where x is a vector of inputs. Let t represent the price of carbon and b represent a vector of emissions factors corresponding to inputs x, so that the cost of the carbon price to the facility is $tb^T x$. The producer minimizes costs so that $C(y, p, t) = min_x\{p^T x + tb^T x : f(x) \geq y; x \geq 0_N\}$. Assuming the $C(y, p, t)$ is differentiable with respect to prices and $f(x)$ is continuous from above, $x^* = \bigtriangledown_p C(y^*, p^*, t) + \frac{\partial C(y^*, p^*, t)}{\partial t} b$. We're interested in carbon emissions, which are simply a function of input demands and emissions factors, so we can write $z^*(y^*, p^*, t) = b^T x^*$. Totally differentiating z with respect to t gives.

$$\frac{dz}{dt} = \sum_{j=1}^{n} b_j \left(\frac{\partial x_j}{\partial y}\frac{dy}{dt} + \sum_{k=1}^{n} \frac{\partial x_j}{\partial p_k}\frac{dp_j}{dt} + \frac{\partial x_i}{\partial t}\frac{dt}{dt} \right) \tag{1}$$

This means changes in carbon emissions due a change in the tax depend on the weighted sum of the carbon tax elasticities of all inputs, which in turn are a function of the output elasticity of the carbon tax, the price and cross-price elasticities of input demand, and the direct impact of the carbon tax on demand for all inputs. We can rearrange the above to write

$$dz = \sum_{j=1}^{n} b_j \frac{\partial x_j}{\partial y} dy + \sum_{j=1}^{n}\sum_{k=1}^{n} \frac{\partial x_j}{\partial p_k} dp_j + \sum_{j=1}^{n} b_j \frac{\partial x_i}{\partial t} dt, \tag{2}$$

and can locally approximate the above by estimating the regression

$$ln(z_i) = \alpha ln(t) + \beta ln(p) + \gamma ln(y_i) + v_i + \epsilon_i, \tag{3}$$

where $\alpha = \sum_{j=1}^{n} b_j \frac{\partial x_i}{\partial t}$, β is a vector whose jth element is $\sum_{j=1}^{n}\sum_{k=1}^{n} b_j \frac{\partial x_j}{\partial p_k}$ and $\gamma = \sum_{j=1}^{n} b_j \frac{\partial x_j}{\partial y}$.

Table 1: Carbon dioxide emissions for all facilities

	Fixed	Random
Log GDP	.042	.007
	(.045)	(.015)
Log EUA Price	-.038***	-.041***
	(.005)	(.004)
Log Natural Gas Price	.137***	.144***
	(.018)	(.016)
Log Coal Price	-.041	-.001
	(.051)	(.025)
Constant	19.332***	19.290***
	(.114)	(.094)
Observations	9374	9374

Confidence Level: *90% **95% ***99%

1.1 Data

Energy price and crack spread data are from Bloomberg and the U.S. Energy Information Administration. Emissions data are from the European Pollutant Release and Transfer Register (E-PRTR). Data on GDP are from the IMF World Economic Outlook database.

1.2 Regression results for all facilities

First, we conduct an economywide regression for all industrial facilities. Unfortunately, facility-specific output data are unavailable, so we use country level GDP as a proxy. This is not a perfect proxy, particularly for exported goods, and for that reason these results should be taken with a grain of salt. However, we can include prices for the primary carbon producing fuels used in industrial facilities: natural gas, fuel oil, and coal. The results are in Table 1. Our sample includes 4,104 facilities, with 1 to 5 years of data for each; the average facility has 2.3 years of data. A hausman test finds the random effects to be consistent, and therefore these results are preferred.

Considering the impact of the carbon price on other pollutants is only slightly more complicated. Since for all fuels, higher carbon is associated with more co-pollutants, the only remaining unknown is the exact relationship between the two, and the manner in which policy changes this relationship. To obtain the overall effect of policy on co-pollutants, we can therefore simply regress the same independent variables on the pollutant in question. The results are in Table 2.

These results are interesting in that the impact of carbon prices on co-pollutants appears to be even larger than for carbon dioxide. However, this is unsurprising when several important factors are considered. First, as discussed in the body of this paper, an $x\%$ decrease in carbon should be associated with *at least* an $x\%$ decrease in co-pollutants assuming air pollution policy is effective. That is, if energy efficiency or

Table 2: Co-pollutant emissions for all facilities

	Sulfur Dioxide	Nitrous Oxides	Particulate Matter
Log GDP	.077	.092*	.101
	(.082)	(.048)	(.142)
Log EUA Price	-.057***	-.032***	-.070***
	(.009)	(.006)	(.017)
Log Natural Gas Price	.244***	.137***	.214***
	(.033)	(.019)	(.059)
Log Coal Price	-.622***	-.359***	-.796***
	(.098)	(.056)	(.178)
Constant	15.082***	13.568***	14.195***
	(.180)	(.120)	(.312)
Observations	6481	12011	2977

Confidence Level: *90% **95% ***99%

production reduction are the chosen abatement strategies, the relative change in carbon dioxide and copollutants should be the same. However, if fuel switching is used in at least one circumstance, the impact on copollutants will be greater than on carbon dioxide. Further, anecdotal evidence suggests that fuel switching was a common compliance tactic for local air pollution policy compliance, and there is reason to believe it would be an appealing strategy for responding to a carbon price as well given its reversibility and relative simplicity. These results can be replicated an reinforced by using the log ratio of a given co-pollutant to carbon dioxide as the dependent variable; policy reduces the copollutant intensity of carbon dioxide emissions in all cases.

The stronger impacts of changes in gas and coal prices on emissions of co-pollutants are also consistent with priors, as this reflects the fact that the difference in co-pollutant intensity between the two fuels is greater than the difference in carbon intensity.

1.3 The Refinery Sector

For the refinery sector, we could just simply repeat the analysis above, dropping non-refineries from the sample. However, focusing on a specific sector allows for greater precision in controlling for output levels. While data on facility level output is unavailable, output and input prices together provide a good proxy. In a market in equlibrium, marginal prices and marginal costs would be equal, meaning the difference between the input and output prices would be determined by the normal rate of profits and would not vary much over time. However, equilibrium is unlikely in the refinery industry. Crude oil prices are notoriously volatile, and demand only slightly less so. Further, refinery capital investments are irreversible, meaning operators are reluctant to adapt their capital to new demands absent a significant premium. Finally, sunk costs mean that equipment no longer consistent with market realities remains in operation. As a result, refinery technology lags in adapting to changes in supply and demand realities.

Table 3: Carbon dioxide emissions for refineries

	Fixed	Random
Log Crack Spread	.100	.118
	(.078)	(.072)
Log GDP	.116	.039
	(.146)	(.060)
Log EUA Price	-.025**	-.020**
	(.011)	(.010)
Log Fuel Oil Price	-.161*	-.122*
	(.090)	(.071)
Log Natural Gas Price	.137**	.107**
	(.066)	(.052)
Constant	19.819***	20.236***
	(.878)	(.399)
Observations	513	513

Confidence Level: *90% **95% ***99%

Crack spreads are a measure of the weighted average of gasoline and diesel prices subtract crude prices. As discussed above, were the refinery sector consistently in equilibrium, crack spreads would not vary significantly over time. However, it is easy to see that they do, in fact, vary quite substantially. High crack spreads mean prices of diesel and gasoline are high relative to crude prices, which means there is a supply shortage. This in turn indicates a shortage of refinery capacity (or at least capacity appropriate to current supply and demand conditions). For this reason, refineries can be expected to be operating at or near capacity when crack spreads are high, since crack spreads mean high margins. Low crack spreads, on the other hand, will lead less competive refineries to operate at reduced capacity or lay dormant.

Since there are fewer refineries than total facilities in the EU, our sample is smaller. We are using data on 208 refineries with 1 to 5 data points each; the mean is 2.5. In some cases random effects were shown to be more efficient than fixed effects, but this did not affect which variables were statistically significant at the levels used. For this reason, we report only fixed effects for consistency.

The results for refineries are qualitatively similar to the economywide figures. However, the differences in scale are interesting. Perhaps most notable is the fact that the impact of emissions permit prices on refinery carbon dioxide emissions appears statistically significantly *weaker* (closer to zero) for refineries than for facilities in general. At the same time, the relationship between permit prices and emissions levels was statistically significantly *stronger* for refineries than for facilities in general. This suggests either that other policy coincident with the EU ETS had a stronger impact on refineries than on other facilities, or that refineries relied on fuel switching as a compliance strategy to a greater extent.

Table 4: Co-pollutant emissions for refineries

	Sulfur Dioxide	Nitrous Oxides	Particulate Matter
Log Crack Spread	.200	.089	-.215
	(.136)	(.123)	(.435)
Log GDP	-.138	.267	.156
	(.271)	(.228)	(.729)
Log EUA Price	-.101***	-.050***	-.118**
	(.022)	(.018)	(.055)
Log Fuel Oil Price	-.443**	-.319**	-.396
	(.172)	(.146)	(.422)
Log Natural Gas Price	.517***	.283***	.690**
	(.124)	(.104)	(.310)
Constant	15.440***	12.061***	10.567**
	(1.604)	(1.361)	(4.341)
Observations	493	540	176

Confidence Level: *90% **95% ***99%