Cold-Ironing as a Cost-Effective Tool for Improving Sustainability in the Shipping Industry

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Master's Project, Spring 2012

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Introduction

The marine transportation sector stands as a major component of the global economy, delivering goods from major producing markets in Asia and the Pacific region to major consumer markets in Europe and North America. The United States Department of Transportation's Maritime Administration recorded over a billion tons of foreign trade through U.S. ports in 2009.[1] With the renovation of the Panama Canal slated for completion in 2014, this intercontinental trade will only increase. Already 37% of global container traffic rides on the post-Panamax ships that are too large for the current canal but will easily pass through the renovated version.[2]

Given the economic importance of this sector, its inclusion in future environmental remediation regimes is key. The Pew Center for the Environment has shown that the shipping sector accounts for 2% of US greenhouse gas emissions. [3]The UK has experienced a similar contribution from shipping at around 1% of ghg emissions in 2004.[4] Shipping also adds substantially to pollutants that impact regional air quality. Near shore shipping transport routes may be responsible for up to 25% of surface ozone formation in Western North America and up to 15% in

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[1] Administration, U.S. Department of Transportation: Marine. "U.S. Waterborne Foreign Trade by U.S. Customs Districts." August 20, 2010 ed2010. < http://www.marad.dot.gov/library_landing_page/data_and_statistics/Data_and_St atistics.htm>
[2] "The Canal Gets Bigger, and U.S. Ports Are Ready." *Business Facilities Magazine* April 1, 2011. Print.
[3] McCollum et. al *Greenhouse Gas Emissions from Aviation and Marine Transportation*. Arlington, VA2009. Print.
[4] Melanie Hobson et. al, Low Carbon Commercial Shipping (Didcot, UK: AEA Energy and Environment, 2007).

Western Europe.[5] The same study points out that shipping can contribute up to 10% of the NOx and SOx emissions in port areas.

Any improvement in the environmental performance of shipping must take into account the fact that requirements that make shipping more expensive relative to other forms of transport would likely result in an overall negative environmental outcome. Marine transport of cargo through forms such as container shipping offers multiples of efficiencies in terms of carbon emissions per weight of goods moved over a given distance. One UK study showed that lamb raised in New Zealand and shipped to Britain via ocean transport was more carbon efficient that lamb raised in-country.[6] A Taiwanese study found that replacing truck routes with maritime shipping routes could improve the profile of transport emissions for goods moving across the island nation of Taiwan.[7] According to the World Shipping Council, moving a ton of cargo from Melbourne, Australia to Southern California generates fewer carbon dioxide emissions than moving the same amount by truck from Dallas to Southern California.[8] Clients of shipping that find movement by boat more expensive may instead choose the much more carbon intensive modes of truck or airplane.

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[5] Dalsoren, S.B. et. al. "Update on Emissions and Environmental Impacts from the International Fleet of Ships: Contribution from Major Ship Types and Ports." *Atmospheric Chemistry and Physics* 9 (2009): 2171-94. Print.

[6] Saunders C, Barber A. *Comparative Energy and Greenhouse Gas Emissions of New Zealand's and the United Kingdom's Dairy Industry.* Christchurch, New Zealnd: Lincoln University, 2007. Print.

[7] Liao, Chun-Hsuing et. al. "Comparing Carbon Dioxide Emissions of Trucking and Intermodal Container Transport in Taiwan." *Transportation Research* 14 (2009): 493-96. Print.

[8] Council, World Shipping. "Low Environmental Impact". 2012. February 12, 2012. <www.worldshipping.org/benefits-of-liner-shipping/low-environmental-impact>.

This analysis seeks to explore options available to the marine shipping industry to meet or raise environmental standards in a cost-effective manner. Within the options considered, the tool of cold-ironing, a process whereby ships plug into shore-side power while in port, has presented itself as a viable cost-effective option for ship owners to reduce emissions while simultaneously experiencing an economic benefit.

Drivers of Sustainability in Shipping

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the principal vehicle for international cooperation to reduce the environmental impact of trans-continental shipping. Countries that are signatories to the convention have the authority to force ships to undergo an inspection to test compliance. This ability for member states to inspect ships operating in their waters came about previously when the 1971 amendments to the International Convention for the Safety of Life at Sea (SOLAS) allowed for such enforcement action to take place. Subsequent conventions such as the International Convention of Training, Certification, and Watchkeeping for Seafarers also allow for port-state control officers to inspect ships.

The International Maritime Organization (IMO), a body under the auspices of the UN, has promulgated multiple iterations of the MARPOL regulations beginning in 1973. The most recent addition to MARPOL is Annex VI, which lays out regulations for the prevention of air pollution from ships. It entered into force in 2005 and covers emissions from ships with a minimum diesel engine size built after 2000. The regulations target nitrogen oxides, sulfur oxides, particulate matter,

volatile organic compounds, and the products from incinerators onboard ships. Annex VI has also created special Emission Control Areas (ECA's) whereby ships operating in these waters must adhere to even stricter emission standards.

Countries that are not signatories to MARPOL or that do not have robust domestic regulations regarding shipping emissions mean that places exist where ship operators can run polluting ships with relative impunity. Currently 62 countries have ratified Annex VI regulations representing just over 84% of the world's tonnage.[9] Even in participating countries the burden of enforcement still falls under the auspices of national authorities rather than any international policing body.

The U.S. Coastguard carries the responsibility of enforcing these regulations for ships operating in waters under its jurisdiction. Annex VI regulations came into force in the U.S. in January 2009 and are part of federal law under 40 CFR part 1043. Ships found not to be in compliance can be fined, detained, or refused entry into port areas. But for older ships and engines engaged in port operations, the EPA has instituted its Clean Ports Initiative to reduce emissions from these coastal industrial areas.[10] Older builds are not covered under MARPOL regulations and reductions in port emissions can come from retrofitting many of the shore-side machines and engines. This is a voluntary program whose main tools include education and funding from grants to improve the impact on air quality from port operations.

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[9] Edmund Hughes, "Marpol Annex Vi-the Ratification Process," (Athens, Greece: International Maritime Organization, 2010), vol. of Marine Environment Division.
[10] United States Environmental Protection Agency, Clean Ports USA, March 18, 2011 2012, Available: www.epa.gov/diesel/ports/.

The EPA can act with force regarding air pollutants under the Clean Air Act and its responsibility in setting National Ambient Air Quality Standards. The impact on shipping becomes clear when one observes that the largest ports by trade volume in the country are also generally found in areas out of attainment for criteria pollutants. Shipping is not solely responsible for these non-attainment issues but can act as a significant contributor, especially with regards to the criteria pollutants of NOx and ozone. In trying to meet these standards regional authorities have worked with port operators to promulgate solutions to reduce emissions. The ports of Los Angeles/Long Beach and NY/NJ have commissioned studies to investigate possible source of emissions reductions.[11][12]

In 2007 the California Air Resources Board approved the Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port. This regulation aimed at reducing NOx and particulate matter emissions from both U.S. and foreign-flagged vessels operating in California ports.[13] The first compliance period begins in 2014 with subsequent compliance periods requiring more stringent reductions. The two main options for compliance involve either using shore-side electric power or implementing some other type of on-board emission reduction technology.

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[11] Corporation, Environ International. *Cold-Ironing Cost Effectiveness Port of Long Beach* Los Angeles, California 2004. Print.
[12] Starcrest Consulting Group, LLC. *Analysis of Vessel Dwelling Emissions and Offset Reduction Measures* 2005. Print.
[13] "Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels at-Berth in a California Port." *17*. Ed. Board, California Air Resources. California Code of Regulations: 2007. Print.

The global market for the shipment of goods constitutes the other significant

driver of environmental improvement within the industry. The International

Standards Organization (ISO) has promulgated its 14040 and 14044 standards that

offer a tool for calculating the GHG emissions of a product.[14] Numerous international

and governmental agencies including UNEP, the World Business Council for

Sustainable Development, and the Japanese Industry of Economy, Trade and

Industry have developed programs for analyzing the environmental footprint of

supply chains.[15] Actors participate in supply chain management because as one

study put it, "the domain of supply chain management offers new opportunities for

creating competitive advantage".[16] Major clients of shipping companies such as

Walmart, OfficeMax, Timberland, and Novartis have instituted green supply chain

policies as part of their corporate sustainability guidelines. Shipping companies

have responded with Maersk acting in some ways as the standard bearer for the

industry. Maersk has begun publishing an annual sustainability action plan to

demonstrate its commitment to high environmental performance and to

differentiate itself from other industry competitors.

Operational and Technological Options

With both market and non-market drivers of sustainability in existence for

marine shipping, a host of technologies and operational solutions have been

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[14] Schmidt, Hans-Jurgen. "Carbon Footprinting, Labelling and Life Cycle Assessment." *International Journal of life Cycle Assessment* 14.Suppl 1 (2008): S6-S9. Print.

[15] Finkbeiner, Matthias. "Carbon Footprinting--Opportunities and Threats." *International Journal of Life Cycle Assessment* 14 (2009): 91-94. Print.

[16] Arlbjorn, Jan Stentoft et. al. "Exploring Supply Chain Innovation." *Logisitics Research* 3 (2010): 3-18. Print.

identified to aid ship operators in meeting the new standards. These measures can be divided into two categories. One category addresses emissions produced during inter-port travel. The other category, and the one of interest here, deals with hotelling emissions. These are emissions that occur while a ship is in port and come mainly from the operation of auxiliary diesel engines for the running of necessary machinery. A report prepared for the Port of Long Beach lays out some of the solutions outside of cold-ironing it considered.[17] What they are and a description of advantages and drawbacks with each option appears as follows:

Table 1 Emissions Reductions Technologies

Technology	Description	Strengths	Weaknesses
Engine Repowering	Major retrofit or replacement of existing engine	Targets all problem emissions	High Cost
Clean Diesel Fuel	Use of specially formulated traditional diesel, bio-diesel	Reduces specific emissions like SOx	Possible high cost, commercial availability, safety issues for use in maritime setting
Combustion Management	Improving combustion operations through	Does not require full engine retrofit	Only certain emissions reduced, Exhaust gas

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[17] Environ International Corporation, <u>Cold-Ironing Cost Effectiveness Port of Long Beach</u> (Los Angeles, California: 2004).

	injection timing delay, exhaust gas recirculation, direct water injection		recirculation may increase some emissions
Exhaust Gas Treatment	Filters, Selective Catalytic Reduction	Effective at reducing NOx emissions	May only reduce NOx emissions
Cryogenic Refrigerated Containers	Containers with perishable cargo have self-supplied power	Reduced emissions across the board, reduced fuel use	Only relevant for specific applications, not commercially viable

The above options do have the overall utility of being able to travel with the ship, as cold-ironing requires some type of shore-side infrastructure. But the overall drawback of them is that they add to operational costs and some are not yet commercially viable. Additionally, only the refrigerated containers will actually substitute away from still having to burn fuel while in port.

Consideration of Cold-Ironing

Over the course of corresponding with Lee Kindbergh, the Director of Environment and Sustainability at Maersk, the company's concern over the coming compliance period for California's Airborne Toxic Control Measure made exploring

the cost-effectiveness of cold-ironing a necessity. Cold-ironing still has some of the drawbacks as the previously mentioned examples as it can consist of a significant capital expenditure for a ship. Cold-ironing can also expose ship operators to spikes in electricity prices. Again, California's push for a 33% renewable portfolio standard will mean increasing electricity prices for customers in that state. This analysis will seek to explore the question of whether operational costs are lower under a business as usual scenario without cold-ironing or whether savings can be realized even with the costs of retrofitting and electricity under cold-ironing deployment.

Factors Involved in a Ship's Power and Fuel Consumption

A hotelling ship must run its auxiliary diesel engines for baseline functions and any machinery necessary for the movement of cargo on and off a ship. Multiple factors then determine the power required by the ship and hence the amount of fuel utilized. Table 1 explains the selected inputs relevant to this analysis.

Table 1

Factor	Description
Ship Capacity in Twenty-foot equivalent unit (TEU)	TEU is the cargo capacity of intermodal containers. Containers on ship determine time in port.
Time in Port Factor[18]	Amount of time per TEU (seconds)
Auxiliary Engine Capacity	Power output of Auxiliary Engines (kw)
Auxiliary Engine Load Factor	Percent of Full Output at which Auxiliary

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[18] Tardif, Louis-Paul. "Measuring Supply Chain Performance: A Government Perspective." Ed. Transport Canada: Toronto, June 18, 2010

	Engines are run
Number of Auxiliary Engines	Different numbers of engines can be used to achieve desired power output.
Engine Fuel Economy	Engine fuel consumption (gallons/hr)
Calls Per Year	Number of visits to port determines annual consumption.

Economic Factors

Determining the cost-effectiveness of cold-ironing must take into account the major factors affecting the cost of operations with and without such an operational change. The major inputs here are cost of petroleum fuel. Ships in port without cold-ironing burn heavy fuel oil or diesel fuel. If cold-ironing technology is utilized, then the cost shifts to the purchase of electricity. Finally, a ship already in existence will have to incur the cost of the retrofit necessary to allow it to use shore-side electric power.

Development of the Model

For this analysis the basic result that determines cost-effectiveness given the previously mentioned factors is whether or not using shore-side power is cheaper. The model to determine this would take into account the cost of powering a ship while in port using auxiliary engines. It would then compare it to the total cost of using shore-side electric power, including the cost of a retrofit.

Part of the inspiration for this model came from a study on the cost-effectiveness of cold-ironing at the Port of Long Beach by Environ in the early

2000's. That study looked at the cost-effectiveness of cold-ironing based on cost per ton of pollutant avoided. The cost included expenditures on the ship and on the shore, essentially providing a budgetary decision for the port authorities rather than the ship operators. At that time, no mention was made of whether cold-ironing would actually save on operating costs as fuel prices still made using auxiliary engines the cheaper option. This analysis will focus on the ships rather than a port as a whole and consider the price of fuel as to whether or not cold-ironing can stand on its economic rather than just its environmental merits.

The estimates for the upfront capital cost of retrofitting a container ship for cold-ironing ranged from $500,000-$700,000.[19] Using the methodology from the study for the Port of Long Beach by Environ, this cost will be amortized over a 10-year project life at a discount rate reflecting the real interest rate of 2.4%. [20] The 10-year project life is a fair assumption, as this study will later look at the costs for Maersk's container fleet. The average entry into service year of the fleet is 2003. With ships having a life of 20-25 years, a 10-year project life appears appropriate. Other determinants of cost on the electricity side include the price of electricity in dollars/kwh, the load factor for the auxiliary engines, number of calls per year, and ship capacity. For fuel costs, the unique determinants come in the form of cost of heavy fuel oil in dollars/gallon, auxiliary engine fuel economy, and the number of engines in operation.

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[19] California Air Resources Board, <u>Draft Report on Cost-Effectiveness of Cold-Ironing at California Ports</u> (2006).
[20] Real Interest Rate (%) taken from The World Bank <http://data.worldbank.org/indicator/FR.INR.RINR>

The fuel and electricity prices used in the deterministic analysis include OECD countries in North America, Europe, and Asia where data was available from the International Energy Agency. This international comparison will allow for a demonstration of how costs change depending on where a ships calls to port. The data range from 2005-2010, which will help illustrate how changing energy prices during the past few years have impacted the cost calculation.

The model appears as follows:

(Ship Capacity*Time in Port Factor*Conversion to hours*Engine Fuel Economy*Number of Operating Engines*Cost of Fuel*Calls Per Year) – (Ship Capacity*Time in Port Factor*Conversion to hours*Number of Operating Engines*Load Per Engine*Load Factor*Cost of Electricity*Calls Per Year+(Annualized Retrofit Cost))

Most of the variables in the above equation can be factored out in order to really explore what the important drivers of cost are. By removing the values that stay constant once a ship is built and conversation factors, the equation appears as follows:

(Number of Operating Engines*Cost of Fuel*Calls Per Year)-(Number of Operating Engines* Cost of Electricity*Calls Per Year+(Annualized Retrofit Cost))

The annualized cost of the retrofit will come from taking the present value of the total cost of the retrofit and solving for the annual payment over the amortized period using the following equation:

Present Value of Retrofit = Annual Payment*((1-(1/1+r)^n)/r))

where r corresponds to the discount rate and n is the number of periods over which the amortization occurs.

Simulation of Varying Inputs

Maersk's portfolio of container ships includes nearly 200 vessels.[21] This number should provide some insight into the fact that a shipping company does not just have one vessel to consider in terms of hotelling costs. Variables like TEU capacity, size and number of engines, and calls to a port may be fairly constant for a single ship but can differ greatly across an entire fleet. To mimic this variance, this analysis will use the Monte Carlo simulation tool in Microsoft Crystal Ball. With this, one can choose a distribution that the selected input most closely follows to attempt to inject more realism into the model outputs. Returning to Maersk's ships, the TEU capacities for its container vessels range from approximately 1,600 to well over 15,000. An operator performing a cost analysis would therefore like to get some idea as to how the costs of switching to cold-ironing would vary across a fleet given changing operational variables. In this analysis the most significant observations will come from examining the variability of fuel prices and operating characteristics and how that impacts the expected value of savings for a fleet of ships.

Deterministic Results of Selected Countries

For this initial deterministic analysis, I sought to show how the costs varied with representative ships of varying size. The countries selected had the most complete data for historic electricity and heavy fuel oil prices. They also provided

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[21] A.P. Moller -Maersk A/S, <u>Maersk Line Vessels</u>, July 4, 2011 2011, Available: http://www.maerskline.com/link/?page=brochure&path=/our_services/vessels, September 1, 2011.
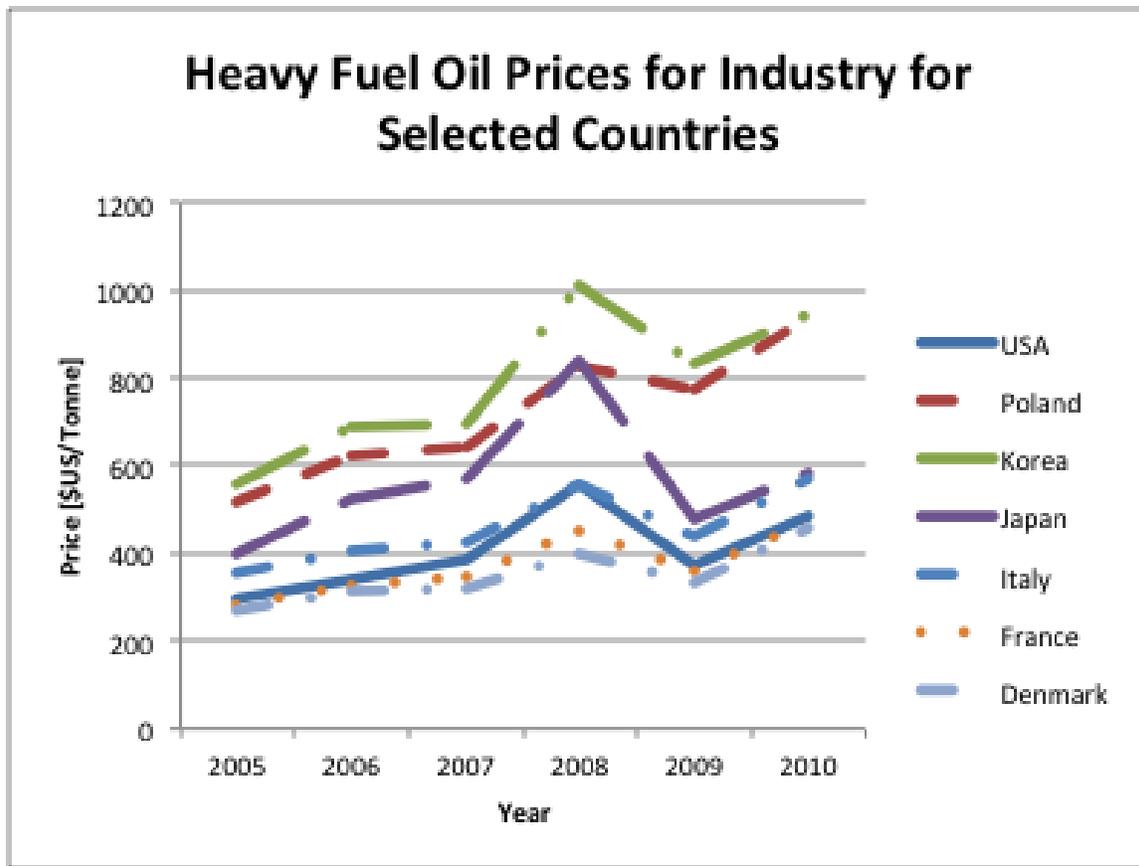
coverage spanning the continents of North America, Europe, and Asia. Figures 1 and
2 demonstrate how electricity and fuel prices varied over the period for which data
was available from IEA.

Figure 1
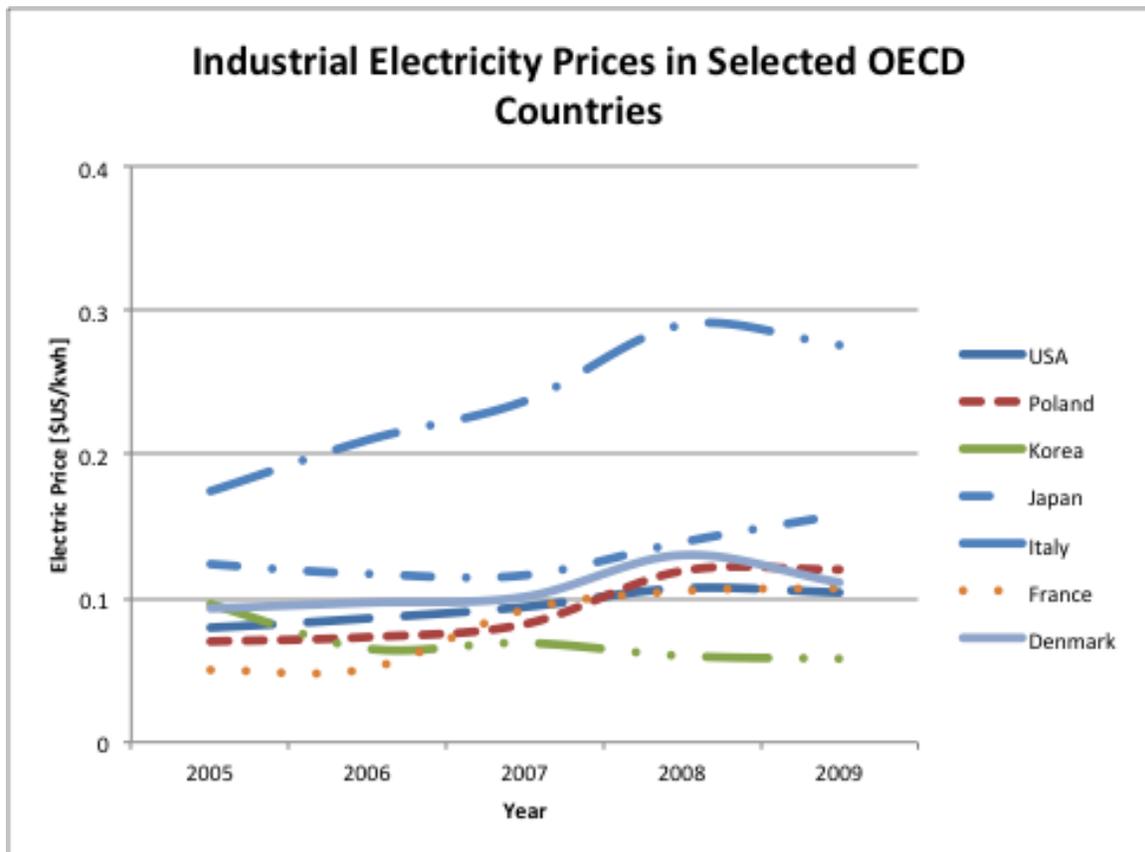
Source: International Energy Agency, *Electricity Information: 2011*

Figure 2

Source: International Energy Agency, *Energy Prices and Taxes: Third Quarter 2011*

The following figures (Figures 3a-3c) illustrate the impact of these changes in prices on the cost analysis for a 4000, 6000, and 8000 TEU ship. All other variables remained constant across the ships. The $700,000 present value for the retrofit was used, which produced an annualized value of $86,303. See Appendix Figure 1 for more detail on the static variables used.
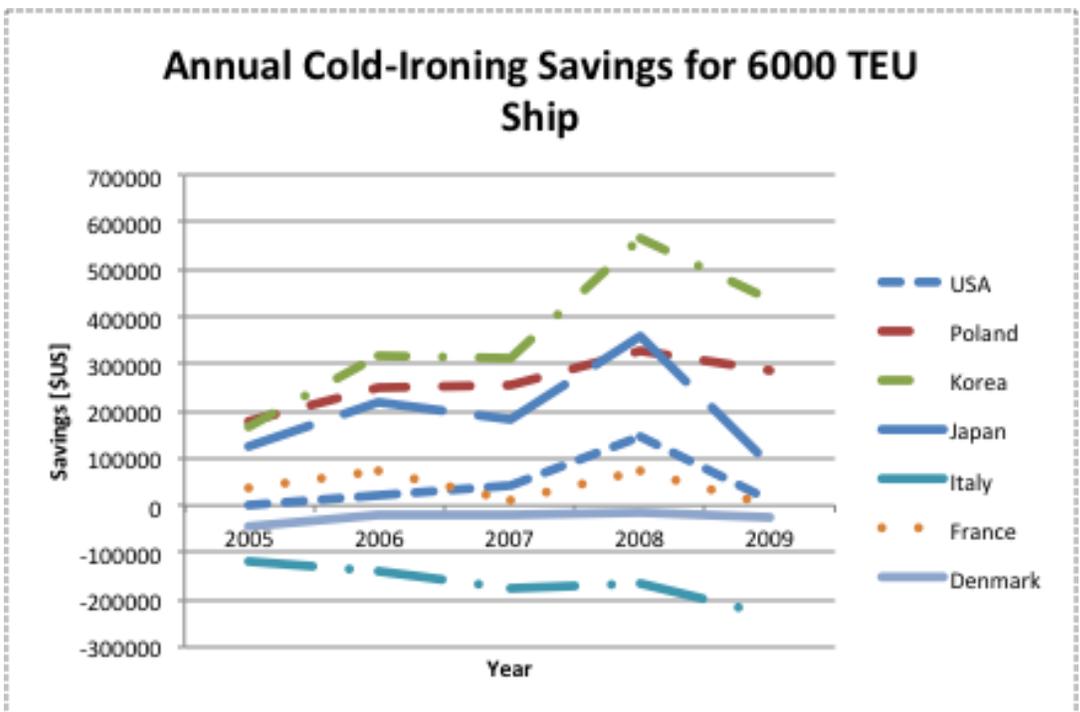
Figure 3a

Figure 3b

Figure 3c

Annual Cold-Ironing Savings for 8000 TEU Ship
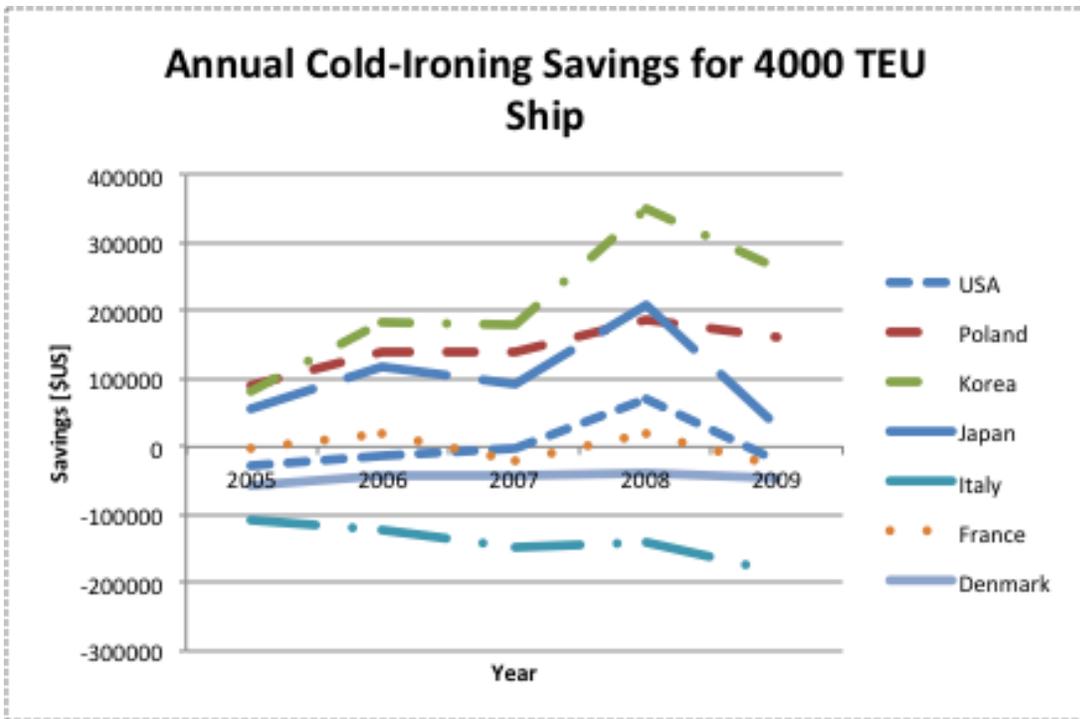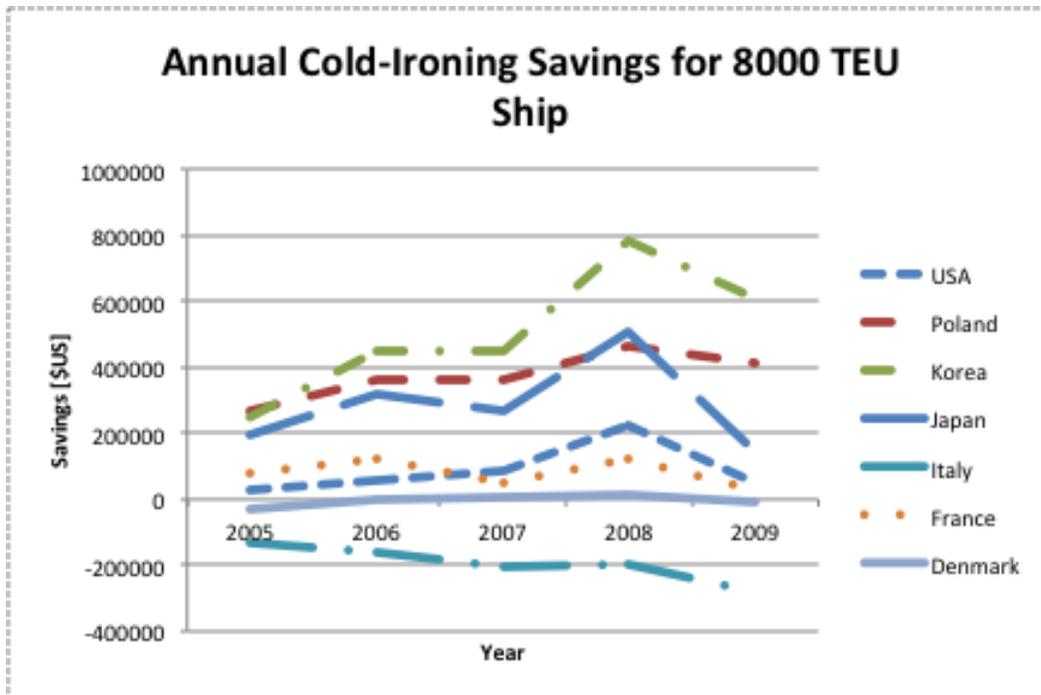

Although electricity prices rose across the period, fuel prices rose at a much greater rate. This equated to a general trend of increasing savings for most of the countries presented. The fall in fuel prices due to a continued weakened global economy in 2009 masked some of the magnitude of this trend. As the size of the ship increased, which means a longer period of time in any given port, this produced increased savings as well. In 2008, a 4000 TEU ship visiting Korean ports eight times over an annual period would have experienced a savings of over $300,000. An 8000 TEU ship in the same year would have seen savings of nearly $800,000.

Monte Carlo Simulation in Crystal Ball

For this part of the analysis, the focus fell on exploring the variation in fuel prices, electricity prices, and ship operating characteristics. Specifically, the operating characteristic of interest here is variation in number of engines in operation on a hotelling ship. Ships can have multiple auxiliary engines to supply

the necessary amount of power on board. Data on fuel and electricity prices are for the U.S. as the EIA and California utilities provided the most complete data sets. The specific mention of California here comes due to the fact that the state's renewable portfolio standard will have a significant impact on electricity prices. The monte carlo simulation used distributions based on the spread of actual data. Table 2 explains the assumptions defining the variables.

Table 2[22]

Variable	Distribution Assigned
U.S. Industrial Electricity Prices	Beta Distribution
Fuel Prices	Beta Distribution
California Electricity Prices (RPS)	Beta Distribution
Number of Engines in Operation	Uniform Discrete Distribution

U.S. electricity prices for industrial users are not expected to vary outside the range of six to seven cents per kilowatt-hour through the outlook period going to 2035.[23] As such the range of expected values for total savings across an entire fleet stays fairly tight. Only the smallest ships in the fleet, those with capacities of 1000 TEU's or less, experience negative savings under this electricity price scenario.

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[22] See appendix for distributions assigned based on Anderson-Darling values from Crystal Ball output. Distribution for engines assumes that selection of number of engines to run can vary with equal probability.

[23] Energy Information Administration. "AEO 2011: Electricity Supply, Disposition, Prices, and Emissions." Ed. Administration, Energy Information. Washington, D.C. 2011. Print.

Figures 4a and 4b show the spread of savings across the fleet and the forecast values
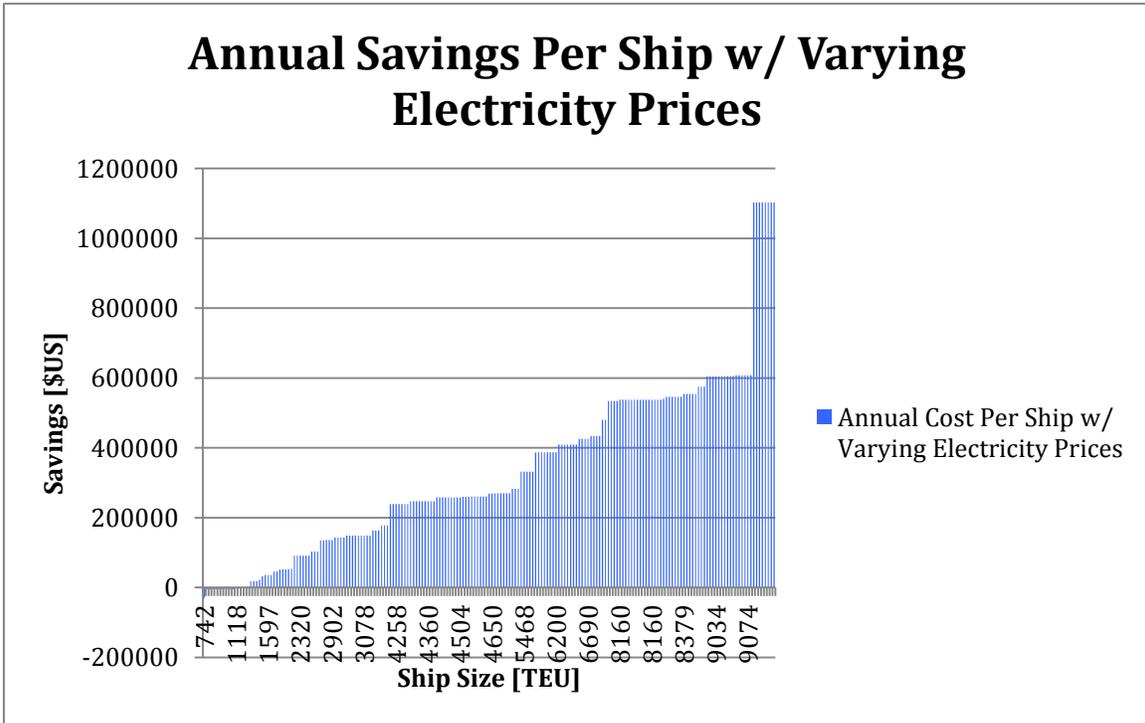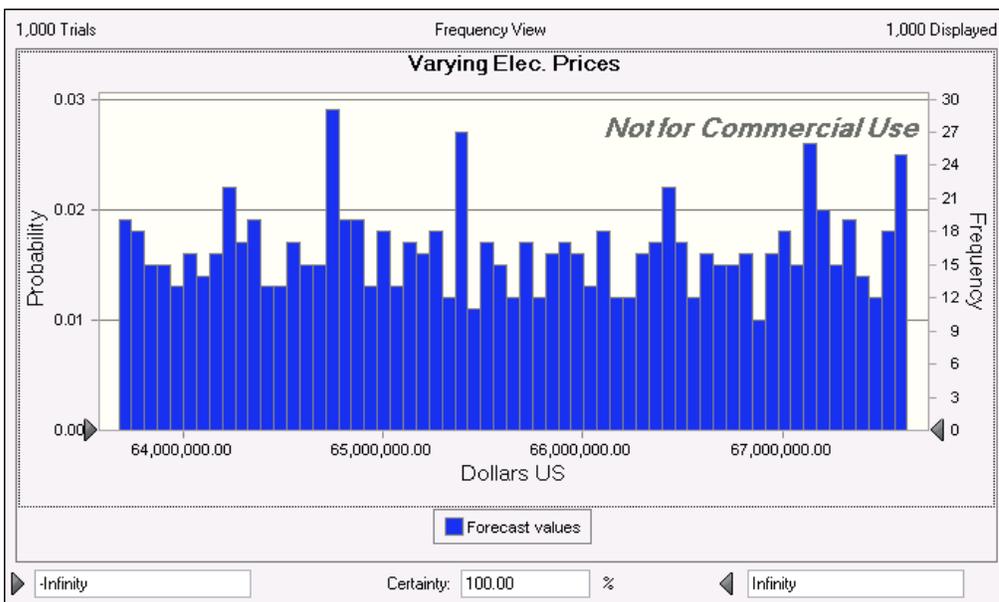from the monte carlo simulation.

Figure 4a

Figure 4b

EIA maintains a record of daily crude oil prices as well as daily diesel prices for the past 25 years. Using this data, I ran a regression to obtain a forecast of diesel prices through 2035.[24] Forecast crude oil prices are expected to rise above $120 per barrel over the next decade with petroleum products following this trajectory.[25] Given this growth, rising fuel prices produced a wider range of savings. The forecast values at the higher end of the range come thanks to the possibility of reaching the very high fuel prices. Figures 5a and 5b show the range of savings across the fleet and the forecast values from the monte carlo simulation.
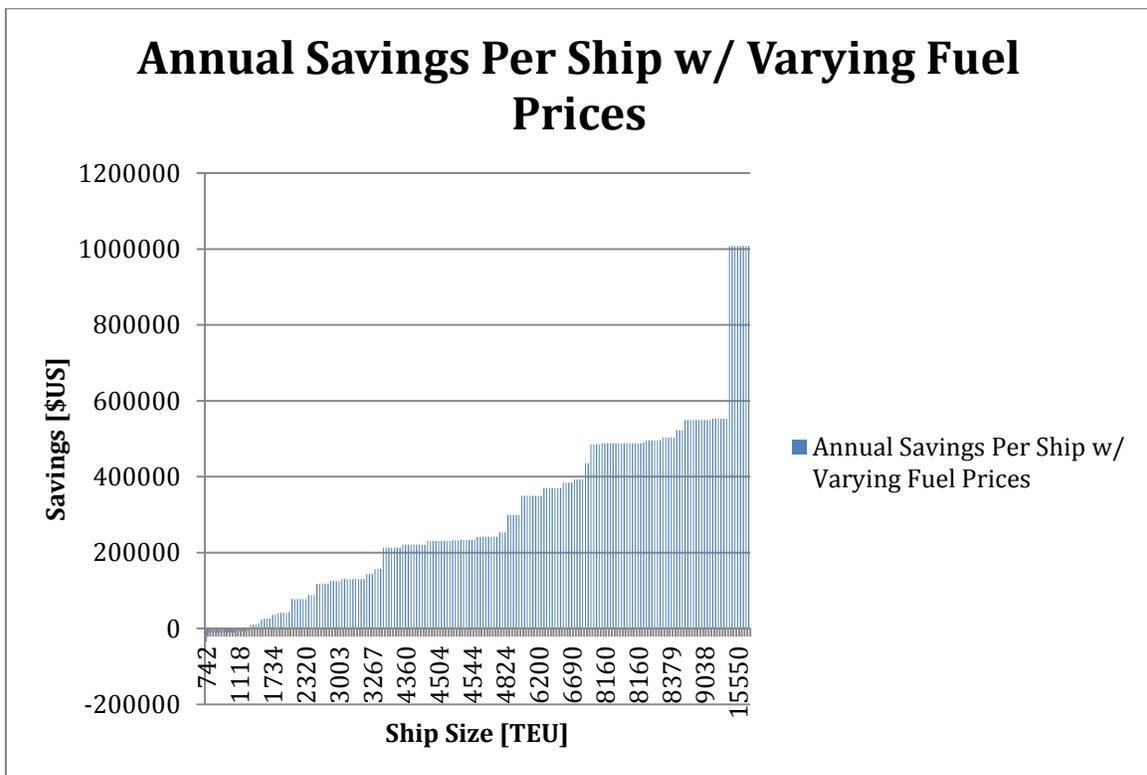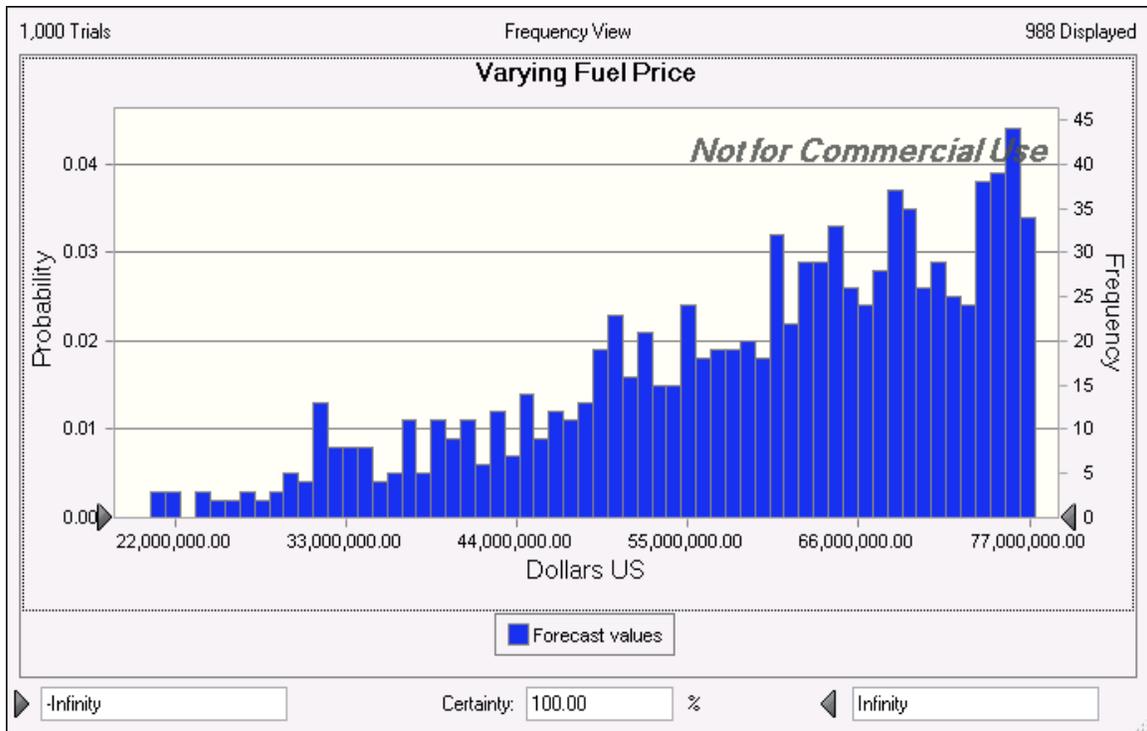
Figure 5a

Figure 5b

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[24] See appendix for regression output.
[25] Energy Information Administration. "AEO 2011: Petroleum Product Prices." Ed. Administration, Energy Information. Washington, D.C. 2011. Print.

To model the impact of varying engine use on a ship, the monte carlo simulation was set to vary between one and three engines in use. This small range in terms of number of engines will allow exploration as to whether cold-ironing still delivers saving when minimal onboard power is required. Figures 6a and 6b demonstrate the spread in savings per ship and forecast values for the whole fleet. With the numbers of engines running at around one, only ships larger than about 1500 TEU's see any savings. The spread of forecast values is also very large with the possibility of seeing no savings for an entire fleet now entering the output.

Figure 6a

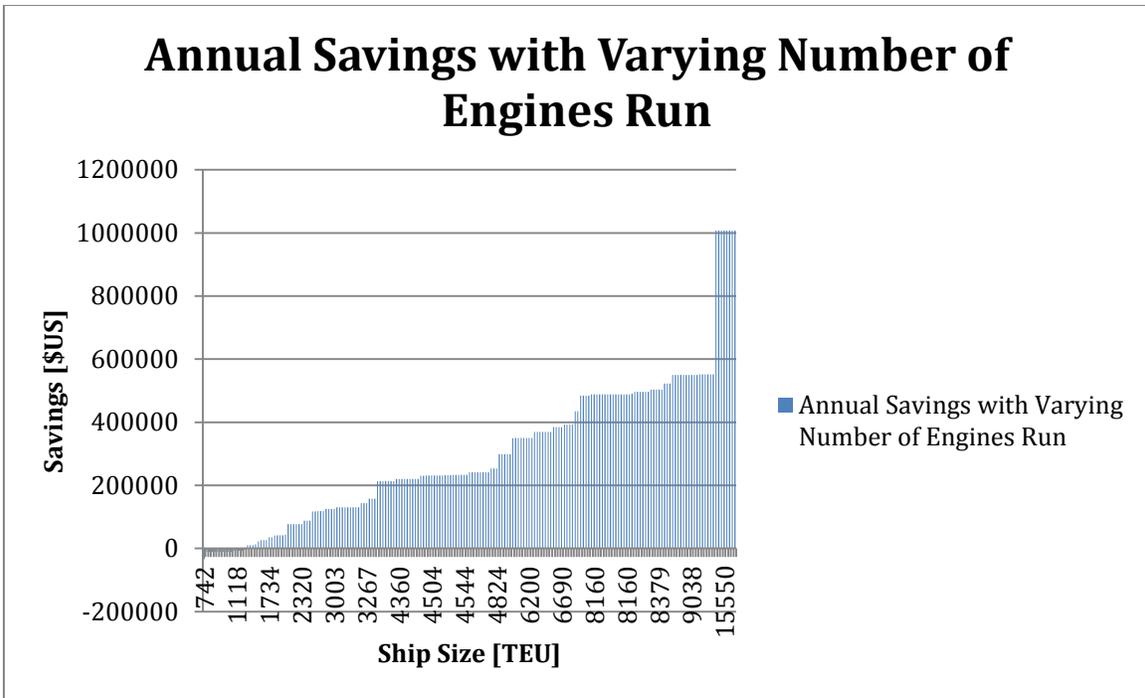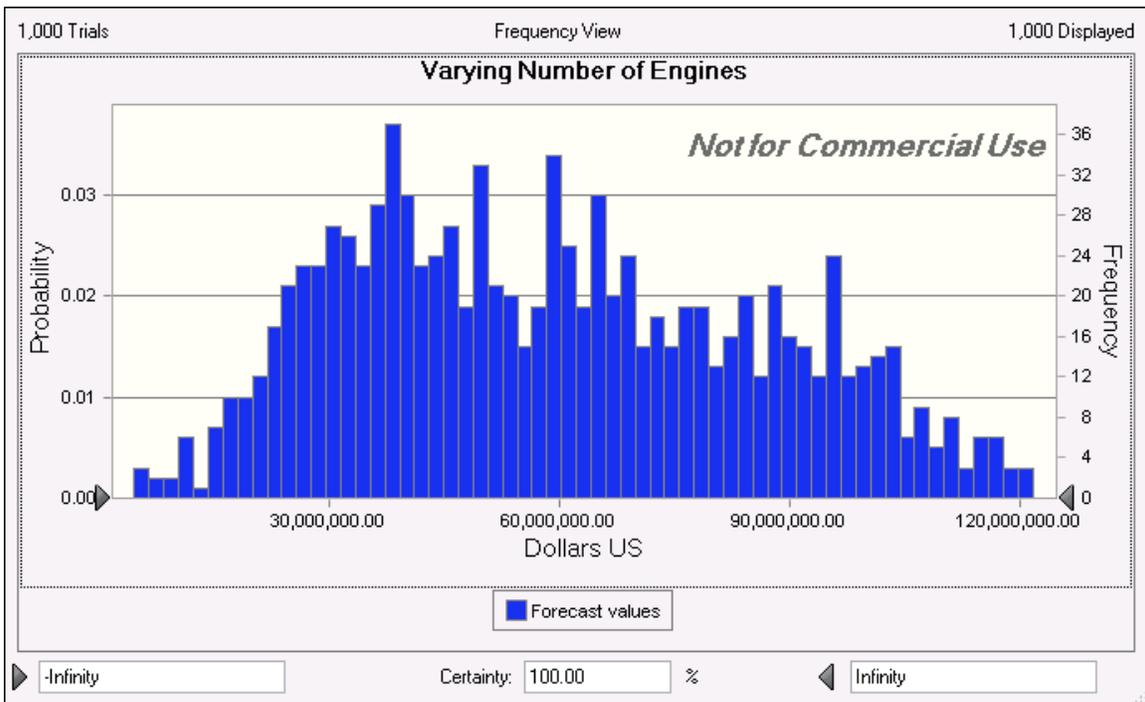**Annual Savings with Varying Number of Engines Run**

Figure 6b

The monte carlo analysis on California electricity prices sought to explore what would happen to savings with a RPS forcing prices to rise more than they otherwise would. The California Public Utilities Commission has forecast that prices will be 16% higher than business-as-usual by 2020 under this standard.[26] To obtain a forecast of prices for California, I used Pacific Gas and Electric's multi-annual industrial historic electricity price series to obtain a regression equation.[27] The 16% increase was then applied to the equation to obtain a forecast of prices. Fuel prices were also allowed to vary according to the forecast used earlier so as to examine the interplay of these variables. Figures 6a and 6b show how even in the face of rising fuel prices, the higher electricity prices make ships even as large as 3000 TEU's experience negative savings. The electricity prices also bring in the possibility of fleet-wide negative savings.

Figure 7a

[26] California Public Utilities Commission. *33% Renewables Portfolio Standard: Implementation Analysis, Preliminary Results*. San Francisco 2009. Print.
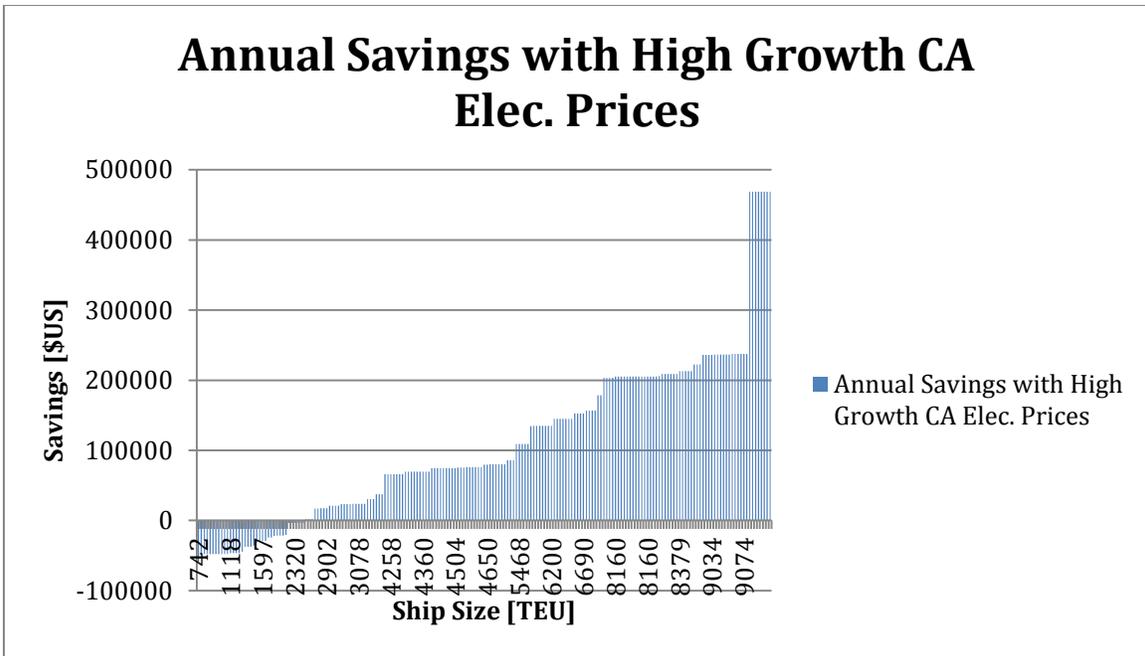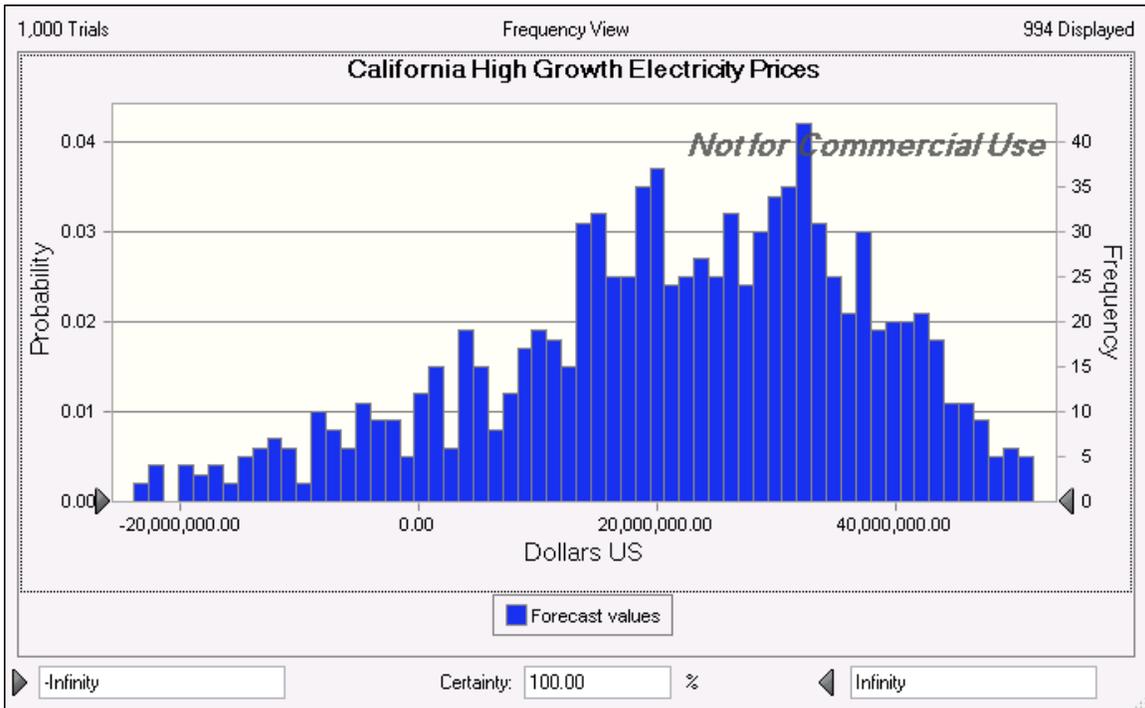[27] See appendix for regression output.

Annual Savings with High Growth CA Elec. Prices

Figure 7b

Sensitivity Analysis

The above results demonstrate how the variation in input prices directly

drives the variation in fleet wide savings. The tight range of predicted electricity

prices for U.S. industrial customers equated to a range of expected values for savings

of approximately $3,000,000. The forecast growth in petroleum and petroleum

product prices lead to a forecast range of over $50,000,000 with a minimum

forecast value of 1/3 the magnitude of the minimum in the electricity scenario.

When electricity and fuel varied, as in the case of the California RPS scenario, Crystal

Ball's output gives some insight into each variable's contribution to variance. Figure

7 gives a graphical representation of this fact.

Figure 8
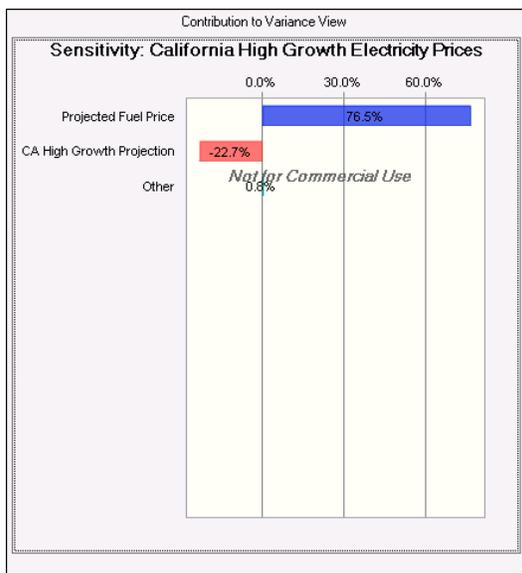
One additional analysis was done to explore what happens when fuel prices,

electricity prices, and engines in operation varied simultaneously. The sensitivity

output showed how the change in ship operating characteristics dominated the

contribution to variance (Figure 8). This should make sense as the scenario that

looked at number of engines in operation alone produced the largest range in

forecast values.

Figure 9
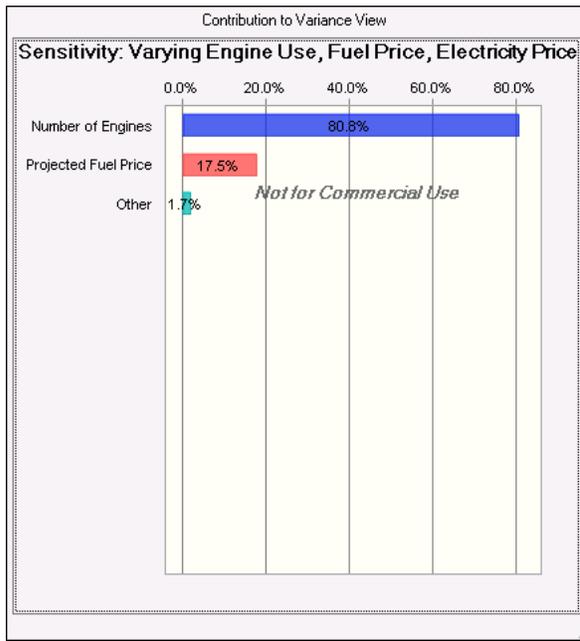
Discussion

Cold-ironing can deliver substantial savings, but the magnitude of these

savings depends on its input prices and operating characteristics. The analysis of

selected countries shows a general positive trend in terms of savings from the use of

cold-ironing in the last half decade. The stochastic analysis demonstrated that even

as liquid fuel prices continue to climb, there might be ships that never see positive

savings. Ports in areas that have renewable electricity standards may add the

increased risk of fleet-wide losses if electricity prices rise high enough. The focus on

these types of standards is that they will not price carbon, making business-as-usual

fuels relatively less expensive than without such a standard. One interesting

observation that the sensitivity analysis uncovered is the strong contribution to

variance that changing operating characteristics, like the number of engines in use, produces. If a shipping company is solely worried about saving on fuel costs without having to switch over to shore-side electricity, exploring how a ship can operate on less power may be an important strategy for cost savings.

The next step in moving forward with cold-ironing lies in the build-up of on-shore infrastructure to provide power to ships. Retrofit costs for ships generally lie in the hundreds of thousands of dollars range, but costs for infrastructure on land could reach into the millions of dollars. Further coordination between shipping companies and port authorities could help move this process forward. Local and national governments have an additional role to play, especially if such work can be folded into emissions reductions for future carbon emissions reductions regimes. California has already moved forward in this sphere by requiring ports to develop plans for shore-side electrification to meet the dual needs of reducing the state's carbon footprint and improving regional air quality.

Finally, the use of renewable power to provide the electricity for ships could even further magnify the positive environmental impacts of cold-ironing. The Port of Gothenburg, Sweden has already engaged in the use of renewable energy by directing excess wind power to supply the needs of its Roll-on/Roll-off ferry terminals.[28] Rather than having to still deal with regional SOx and NOx emissions from traditional power plants supplying power to ports, albeit at a greatly reduced level, these emissions could disappear altogether with the use of renewable power.

Conclusion

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[28] Corporation, Environ International. *Cold-Ironing Cost Effectiveness Port of Long Beach* Los Angeles, California: 2004. Print.

The ultimate responsibility of a corporation is to increase the equity stake of its shareholders. At times, addressing environmental concerns and improving sustainability for private actors confronts this requirement if it means an increase in costs. Most of the options available for improving sustainability in shipping companies in the past have meant an increase in costs. But with the recent and possible future movement in energy prices, cold-ironing could pose a huge economic and environmental boon to the industry.

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APPENDIX

Appendix Figure 1

	Quantity	Unit
Ship Size	4000	TEU
Fuel Consumption		
Time in Port Factor	51	sec/TEU
Auxiliary Engine Size	2000	kw
Engine Fuel Economy	130	gallons/hr
Number of Engines	2	
Engine Load Factor	0.63	
Annualized Retrofit Cost	86303	$US

Appendix Figure 2

regress Diesel Crude Year

```
    Source |     SS      df      MS            Number of obs =   3993

-------------+------------------------------        F( 2,  3990) =69097.19

     Model |  2962.8718    2  1481.4359          Prob > F      = 0.0000

  Residual |  85.5451481  3990 .021439887          R-squared    = 0.9719

-------------+------------------------------        Adj R-squared =  0.9719

     Total |  3048.41695  3992 .763631501          Root MSE     = .14642
```

```
--------------------------------------------------------------------------
    Diesel |    Coef.  Std. Err.    t   P>|t|    [95% Conf. Interval]
-------------+------------------------------------------------------------
    Crude |   .029504  .0001596  184.84  0.000     .029191   .0298169
    Year |  -.0020794  .0010208   -2.04  0.042   -.0040807   -.000078
    _cons |   4.21915  2.038656    2.07  0.039    .2222457   8.216054
```
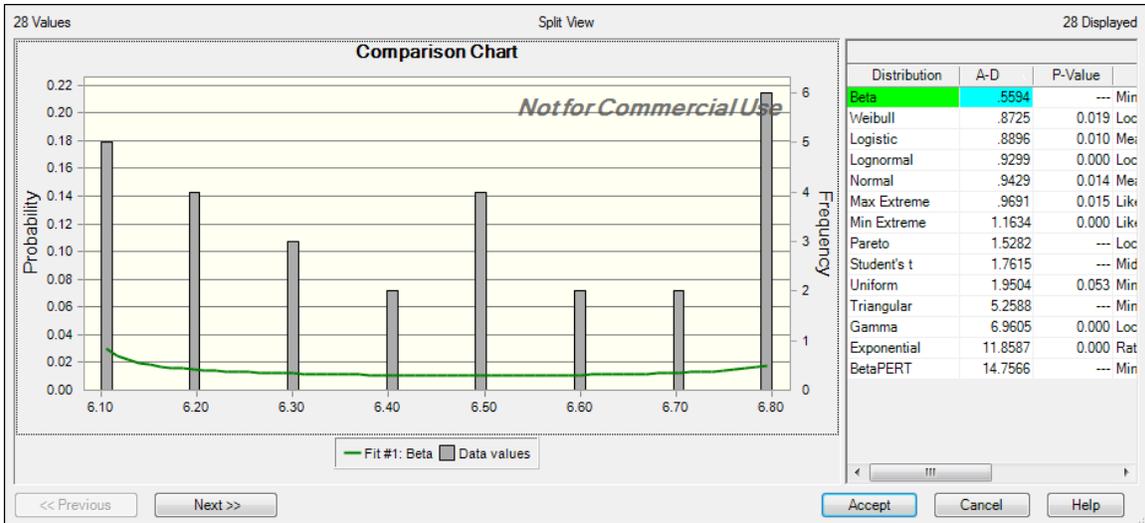
Appendix Figure 3

. regress eprice Year

```
    Source |     SS      df     MS          Number of obs =     34
-------------+----------------------------        F( 1,   32) =  29.95
    Model |  .002433361    1  .002433361        Prob > F    = 0.0000
  Residual |  .002600282   32  .000081259        R-squared   = 0.4834
-------------+----------------------------        Adj R-squared = 0.4673
    Total |  .005033642   33  .000152535        Root MSE    = .00901
```

```
--------------------------------------------------------------------------
    eprice |    Coef.  Std. Err.    t   P>|t|    [95% Conf. Interval]
-------------+------------------------------------------------------------
    Year |   .0029181  .0005333    5.47  0.000    .0018319   .0040043
    _cons |  -5.748434  1.070046   -5.37  0.000   -7.928046  -3.568822
```
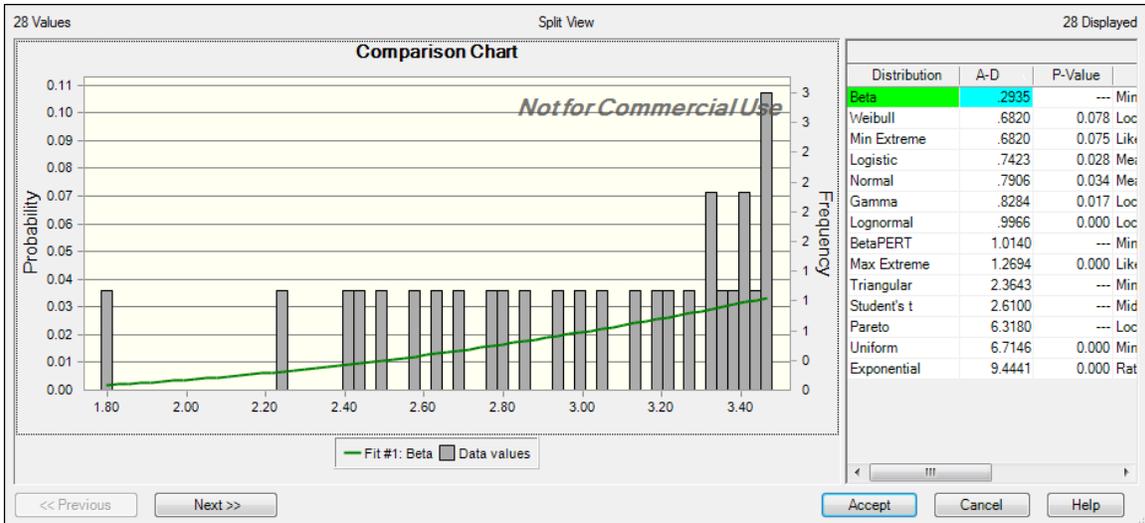
Appendix Figure 4

U.S. Industrial Electricity Price Distribution

Appendix Figure 5

Fuel Price Distribution

Appendix Figure 6

California Electricity Prices (RPS High Growth Scenario)