Proposal to Designate an Emission Control Area for Nitrogen Oxides, Sulfur Oxides and Particulate Matter

Technical Support Document

Chapter 6
Economic Impacts

Assessment and Standards Division
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6 Economic Impacts

Chapter 5 provides the engineering costs associated with complying with the Tier III NO_X limits and the ECA fuel sulfur limits for all ships operating in the U.S. portion of the proposed ECA in 2020. In this chapter, we examine the economic impacts of these costs on shipping engaged in international trade. We look at two aspects of the economic impacts: estimated social costs and how they are shared across stakeholders, and estimated market impacts in terms of changes in prices and quantities produced for directly affected markets. All costs are presented in terms of 2006 U.S. dollars.

The total estimated social costs associated with the U.S. portion of the proposed ECA in 2020 are equivalent to the estimated compliance costs of the program, at approximately $2.78 billion. These costs are expected to accrue initially to the owners and operators of affected vessels. These owners and operators are expected to pass their increased costs on to the entities that purchase their transportation services in the form of higher freight rates. Ultimately, these costs will be borne by the final consumers of goods transported by ocean-going vessels in the form of higher prices for those goods.

The compliance costs associated with the U.S. portion of the proposed ECA are described earlier in this chapter. We estimate that these costs added to the total cost of shipping goods to or from a U.S. origin or destination will result in only a modest increase in the costs of goods transported by ship. We estimate that the cost to comply with the ECA requirements would increase the price of a new vessel by 2 percent or less. With regard to operating costs, analysis of a ship in liner service between Singapore, Seattle, and Los Angeles/Long Beach, which includes about 1,700 nm of operation in the proposed ECA, suggests that improving from current performance to ECA standards would increase the operating costs by about 3 percent. For a container ship, this represents a price increase of about $18 per container, assuming the total increase in operating costs is passed on to the purchaser of marine transportation services. This would be about a 3 percent price increase. The per passenger price of a seven-day Alaska cruise operating entirely within the ECA is expected to increase about $7 per day. For ships that spend less time in the ECA, the expected increase in total operating costs would be smaller.

It should be noted that this economic analysis holds all other aspects of the market constant except for the designation of the proposed ECA. It does not attempt to predict the equilibrium market conditions for 2020, particularly with respect to how excess capacity in today’s market due to the current economic downturn will be absorbed. This approach is appropriate because the goal of an economic impact analysis is to explore the impacts of a specific program; allowing changes in other market conditions would confuse the impacts due to the proposed regulatory program.

The remainder of this chapter provides detailed information on the methodology we used to estimate these economic impacts and the results of our analysis.

6.1 The Purpose of an Economic Impact Analysis

An Economic Impact Analysis (EIA) is prepared to provide information about the potential economic consequences of a regulatory action. Such an analysis consists of estimating the social costs of a regulatory program and the distribution of these costs across stakeholders.

In an economic impact analysis, social costs are the value of the goods and services lost by society resulting from a) the use of resources to comply with and implement a regulation and b) reductions in output. There are two parts to the analysis. In the economic welfare analysis, we look at the total social costs associated with the program and their distribution across key stakeholders. In the market analysis, we estimate how prices and quantities of goods and directly affected by the emission control program can be expected to change once the program goes into effect.

6.2 Economic Impact Analysis Methodology

Economic impact analysis is rooted in basic microeconomic theory. We use the laws of supply and demand to simulate how markets can be expected to respond to increases in production costs that occur as a result of the new emission control program. Using that information, we construct the social costs of the program and identify how those costs will be shared across the markets and, thus, across stakeholders. The relevant concepts are summarized below and are presented in greater detail in Appendix 6A to this chapter.

Before the implementation of a control program, a market is assumed to be in equilibrium, with producers producing the amount of a good that consumers desire to purchase at the market price. The implementation of a control program results in an increase in production costs by the amount of the compliance costs. This generates a “shock” to the initial equilibrium market conditions (a change in supply). Producers of affected products will try to pass some or all of the increased production costs on to the consumers of these goods through price increases, without changing the quantity produced. In response to the price increases, consumers will decrease the quantity they buy of the affected good (a change in the quantity demanded). This creates surplus production at the new price. Producers will react to the decrease in quantity demanded by reducing the quantity they produce, and they will be willing to sell the remaining production at a lower price that does not cover the full amount of the compliance costs. Consumers will then react to this new price. These interactions continue until the surplus is removed and a new market equilibrium price and quantity combination is achieved.

The amount of the compliance costs that will be borne by stakeholders is ultimately limited by the price sensitivity of consumers and producers in the relevant market, represented by the price elasticities of demand and supply for each market. An “inelastic” price elasticity (less than one) means that supply or demand is not very responsive to price changes (a one percent change in price leads to less than one percent change in quantity). An “elastic” price elasticity (more than one) means that supply or demand is sensitive to price changes (a one percent change in price leads to more than one percent change in quantity). A price elasticity of one is unit elastic, meaning there is a one-to-one correspondence between a percent change in price and percent change in quantity.

On the production side, price elasticity of supply depends on the time available to adjust production in response to a change in price, how easy it is to store goods, and the cost of increasing (or decreasing) output. In this analysis we assume the supply for engines, vessels, and marine transportation services is elastic: an increase in the market price of an engine, vessel or freight rates will lead producers to want to produce more, while a decrease will lead them to produce less (this is the classic upward-sloping supply curve). It would be difficult to estimate the slope of the supply curve for each of these markets given the global nature of the sector. However, it is reasonable to assume that the supply elasticity for the ocean marine transportation services market is likely to be greater than one. This is because output can more easily be adjusted due to a change in price. For the same reason, the supply elasticity for the new Category 3 engine market is also likely to be greater than one, especially since these engines are often used in other land-based industries, especially in power plants. The supply elasticity for the vessel construction market, on the other hand, may be less than or equal to one, depending on the vessel type, since it may be harder to adjust production and/or store output if the price drops, or rapidly increase production if the price increases. Because of the nature of this industry, it would not be possible to easily switch production to other goods, or to stop or start production of new vessels.

On the consumption side, we assume that the demand for engines is a function of the demand for vessels, which is a function of the demand for international shipping (demand for engines and vessels is derived from the demand for marine transportation services). This makes intuitive sense: Category 3 engine and ocean-going vessel manufacturers would not be expected to build an engine or vessel unless there is a purchaser, and purchasers will want a new vessel/engine only if there is a need for one to supply marine transportation services. Deriving the price elasticity of demand for the vessel and engine markets from the international shipping market is an important feature of this analysis because it provides a link between the product markets.

In this analysis, the price elasticity of demand is nearly perfectly inelastic. This stems from the fact that, that, for most goods, there are no reasonable alternative shipping modes. In most cases, transportation by rail or truck is not feasible, and transportation by aircraft is too expensive. Approximately 90 percent of world trade by tonnage is moved by ship, and ships provide the most efficient method to transport these goods on a tonne-mile basis.[1] Stopford notes that "shippers need the cargo and, until they have time to make alternative arrangements, must ship it regardless of cost … The fact that freight generally accounts for only a small portion of material costs reinforces this argument."[2] A nearly perfectly inelastic price elasticity of demand for marine transportation services means that virtually all of the compliance costs can be expected to be passed on to the consumers of marine transportation services, with no change in output for engine producers, ship builders, or owners and operators of ships engaged in international trade.

The economic impacts described below rely on the estimated engineering compliance costs presented in Chapter 5. These include the cost of hardware for new vessels to comply with the Tier III engine standards, and the cost of fuel switching equipment for certain new and existing vessels. Also included are expected increases in operating costs for vessels operating in the ECA. These increased operating costs include changes in fuel consumption rates, increases in fuel costs, and the use of urea for engines equipped with SCR, as well as a small increase in operating costs for operation outside the ECA due to the fuel price impacts of the program.

6.3 Expected Economic Impacts of the Proposed ECA

6.3.1 Engine and Vessel Market Impacts

The assumption of nearly perfectly inelastic demand for marine transportation services means that the amount of these services purchased is not expected to change as a result of costs of complying with the ECA requirements in the U.S. portion of the proposed ECA. As a result, the demand for vessels and engines would also not change compared to the no-control scenario, and the quantities produced would stay the same in 2020.

Also due to the assumption of nearly perfectly inelastic demand for marine transportation services, the price impacts would be equivalent to the engineering compliance costs for the new engine and vessel markets. Estimated price impacts for a sample of engine and vessel combinations are set out in Table 6.3-1, for medium speed engines, and Table 6.3-2, for slow speed engines.

Table 6.3-1 Summary of Estimated Market Impacts – New Medium Speed Engines and Vessels (2020; $2006)

SHIP TYPE	AVERAGE PROPULSION POWER	NEW VESSEL ENGINE PRICE IMPACT (NEW TIER III ENGINE PRICE IMPACT)[A]	NEW VESSEL FUEL SWITCHING EQUIPMENT PRICE IMPACT[B]	NEW VESSEL TOTAL PRICE IMPACT
Auto Carrier	9,600	$573,200	$42,300	$615,500
Bulk Carrier	6,400	$483,500	$36,900	$520,400
Container	13,900	$687,800	$49,200	$736,000
General Cargo	5,200	$450,300	$34,900	$475,200
Passenger	23,800	$952,500	$65,400	$1,107,900
Reefer	7,400	$511,000	$38,500	$549,500
RoRo	8,600	$543,800	$40,500	$584,300
Tanker	6,700	$492,800	$37,400	$530,200
Misc.	9,400	$566,800	$41,900	$608,700

[a] Medium speed engine price impacts are estimated from the cost information presented in Chapter 5 using the following formula: (10%*($/SHIP_MECH→CR))+(30%*($/SHIP_ELEC→CR))+(T3 ENGINE MODS)+(T3SCR))
[b] Assumes 32 percent of new vessels would require the fuel switching equipment.

These price impacts reflect the impacts of the costs that will be incurred when the most stringent ECA standards are in place in 2020. These estimated price impacts are small when compared to the price of a new vessel.

Table 6.3-2 Summary of Estimated Market Impacts – Slow Speed Engines and Vessels (2020; $2006)

SHIP TYPE	AVERAGE PROPULSION POWER	NEW VESSEL ENGINE PRICE IMPACT (NEW ENGINE PRICE IMPACT)[A]	NEW VESSEL FUEL SWITCHING EQUIPMENT PRICE IMPACT[B]	NEW VESSEL TOTAL PRICE IMPACT
Auto Carrier	11,300	$825,000	$48,000	$873,000
Bulk Carrier	8,400	$672,600	$42,700	$715,300
Container	27,500	$1,533,100	$63,900	$1,597,000
General Cargo	7,700	$632,900	$41,000	$673,900
Passenger	23,600	$1,385,300	$61,200	$1,446,500
Reefer	10,400	$781,000	$46,500	$827,500
RoRo	15,700	$1,042,100	$53,900	$1,096,000
Tanker	9,800	$744,200	$45,300	$789,500
Misc.	4,700	$453,600	$32,000	$485,600

[a] Slow speed engine price impacts are estimated from the cost information presented in Chapter 5 using the following formula: (5%*($/SHIP_MECH→CR))+(15%*($/SHIP_ELEC→CR))+(T3 ENGINE MODS)+(T3 SCR))

[b] Assumes 32 percent of new vessels would require the fuel switching equipment

A selection of new vessel prices is provided in Table 6.3-3, and range from about $40 million to $480 million. The program price increases range from about $600,000 to $1.5 million. A price increase of $600,000 to comply with the ECA requirements would be an increase of approximately 2 percent for a $40 million vessel. The largest vessel price increase noted above, for a passenger vessels, is about $1.5 million; this is a price increase of less than 1 percent for a $478 million passenger vessel. Independent of the nearly perfect inelasticity of demand, price increases of this magnitude would be expected to have little, if any, effect on the quantity sales of new vessels, all other economic conditions held constant.

Table 6.3-3 Newbuild Vessel Price by Ship Type and Size, Selected Vessels (Millions, $2008)

VESSEL TYPE	**VESSEL SIZE CATEGORY**	**SIZE RANGE (MEAN) (DWT)**	**NEWBUILD**
Bulk Carrier	Handy	10,095 – 39,990 (27,593)	$56.00
	Handymax	40,009 – 54,881 (47,616)	$79.00
	Panamax	55,000 – 78,932 (69,691)	$97.00
	Capesize	80,000 – 364,767 (157,804)	$175.00
Container	Feeder	1,000-13,966 (9,053)	$38.00
	Intermediate	14,003-36,937 (24,775)	$70.00
	Panamax	37,042-54,700 (45,104)	$130.00
	Post Panamax	55,238-84,900 (67,216)	$165.00
Gas carrier	Midsize	1,001-34,800 (7,048)	$79.70
	LGC	35,760-59,421 (50,796)	$37.50
	VLGC	62,510-122,079 (77,898)	$207.70
General cargo	Coastal Small	1,000-9,999 (3,789)	$33.00
	Coastal Large	10,000-24,912 (15,673)	$43.00
	Handy	25,082-37,865 (29,869)	$52.00
	Panamax	41,600-49,370 (44,511)	$58.00

VESSEL TYPE	VESSEL SIZE CATEGORY	SIZE RANGE (MEAN) (DWT)	NEWBUILD
Passenger	All	1,000–19,189 (6,010)	$478.40
Reefer	All	1,000–19,126 (6,561)	$17.30
Ro-Ro	All	1,000–19,126 (7,819)	$41.20
Tanker	Coastal	1,000-23,853 (7,118)	$20.80
	Handymax	25,000-39,999 (34,422)	$59.00
	Panamax	40,000-75,992 (52,300)	$63.00
	AFRAmax	76,000-117,153 (103,112)	$77.00
	Suezmax	121,109-167,294 (153,445)	$95.00
	VLCC	180,377-319,994 (294,475)	$154.00
Sources: Lloyd’s Shipping Economist (2008), Informa (2008), Lloyd’s Sea-Web (2008)			

6.3.2 Fuel Market Impacts

The market impacts for the fuel markets were estimated through the modeling performed to estimate the fuel compliance costs for the coordinated strategy. In the WORLD model, the total quantity of fuel used is held constant, which is consistent with the assumption that the demand for international shipping transportation would not be expected to change due to the lack of transportation alternatives.

The expected price impacts of the coordinated program are set out in Table 6.3-4. Note that on a mass basis, less distillate than residual fuel is needed to go the same distance (5 percent less). The prices in Table 6.3-4 are adjusted for this impact.

Table 6.3-4 shows that the coordinated strategy is expected to result in a small increase in the price of marine distillate fuel, about 1.3 percent. The price of residual fuel is expected to decrease slightly, by less than one percent, due to a reduction in demand for that fuel.

Table 6.3-4 Summary of Estimated Market Impacts - Fuel Markets

FUEL	UNITS	BASELINE PRICE	CONTROL PRICE	ADJUSTED FOR ENERGY DENSITY	% CHANGE
Distillate	$/tonne	$462	$468	N/A	+1.3%
Residual	$/tonne	$322	$321	N/A	-0.3%
Fuel Switching	$/tonne	$322	$468	$444	+38.9%

Because of the need to shift from residual fuel to distillate fuel in the ECA, ship owners are expected to see an increase in their total cost of fuel. This increase is because distillate fuel is more expensive than residual fuel. Factoring in the higher energy content of distillate fuel, relative to residual fuel, the fuel cost increase would be about 39 percent.

6.3.3 Marine Transportation Market Impacts

We used the above information to estimate the impacts on the prices of marine transportation services. This analysis, presented in Appendix 6B to this chapter, is limited to the impacts of increases in operating costs due to the fuel and emission requirements of the coordinated strategy. Operating costs would increase due to the increase in the price of fuel, the need to switch to fuel with a sulfur content not to exceed 1,000 ppm while operating in the ECA, and due to the need to dose the aftertreatment system with urea to meet the Tier III standards.

Estimates of the impacts of these increased operating costs were performed using a representative fleet, fuel cost, actual operational parameters, and sea-route data for three types of ocean going vessels: container, bulk carrier, and cruise liner. The representative fleet values used were obtained from the Lloyd's of London Sea-Web Database, and were based on actual vessel size (Dead Weight Tonnes (DWT)) and engine power (kilowatt – hour (kW-hr)) of each vessel type. Additionally, to develop a representative sea-route for our price estimations, we created two theoretical trips, a 'circle route' occurring in the Pacific Ocean and an Alaskan cruise. The total nautical mileage (nm) for the 'circle route' was determined to be 15,876 nm, with approximately 1,700 nm occurring within the proposed U.S. ECA boundary, while the Alaskan voyage travelled up the Canadian / Alaskan coastline for seven days, stopping at five destinations, and operating completely in the proposed ECA for a total of 2,000 nm. We also estimated the impacts for a trip to the port at Montreal (1,000 nm).

To conduct our price increase estimations, we calculated the average fuel operational costs of the theoretical 'circle route' for the container and bulk carrier, and the Alaskan voyage for the cruise liner as they would function today, completely on residual fuel. We then calculated the operational fuel costs for the vessels if they were to travel the route with the U.S. ECA in place. This ECA calculation was conducted assuming that the vessel would continue to operate on residual fuel when outside of the ECA, and that approximately 33 percent of these vessels would also use an exhaust aftertreatment technology that would require urea usage.

The overall price differences for each of these hypothetical trips were obtained by subtracting the residual fuel operational costs from the calculated ECA operational fuel / urea costs. Table 6.3-5 summarizes these price increases as they relate to goods shipped and per-passenger impacts. Additionally, the table lists the vessel and engine parameters that were used in the calculations.

Table 6.3-5 Summary of Impacts of Operational Fuel / Urea Cost Increases

VESSEL TYPE	VESSEL AND ENGINE PARAMETERS	OPERATIONAL PRICE INCREASES
Container North Pacific Circle Route	36,540 kW 50,814 DWT	$17.53/TEU
Bulk Carrier North Pacific Circle Route	3,825 kW 16,600 DWT	$0.56 / tonne
Cruise Liner (Alaska)	31,500 kW 226,000 DWT 1,886 passengers	$6.60 / per passenger per day

This information suggests that the increase in marine transportation service prices would be small, both absolutely and when compared to the price charged by the ship owner per unit transported. For example, Stopford notes that the price of transporting a 20 foot container between the UK and Canada is estimated to be about $1,500; of that, $700 is the cost of the ocean freight; the rest is for port, terminal, and other charges.[3] An increase of about $18 represents an increase of less than 3 percent of ocean freight cost, and about one percent of transportation cost. Similarly, the price of a 7-day Alaska cruise varies from $100 to $400 per night or more. In that case, this price increase would range from 1.5 percent to about 6 percent.

Our analysis also suggests that increases in operational costs of the magnitude expected to occur for vessels operating in the ECA are within the range of historic price variations for bunker fuel. This is illustrated in Figure 6.3-1. This figure is based on variation in fuel price among the ports of Singapore, Houston, Rotterdam, and Fujairah.

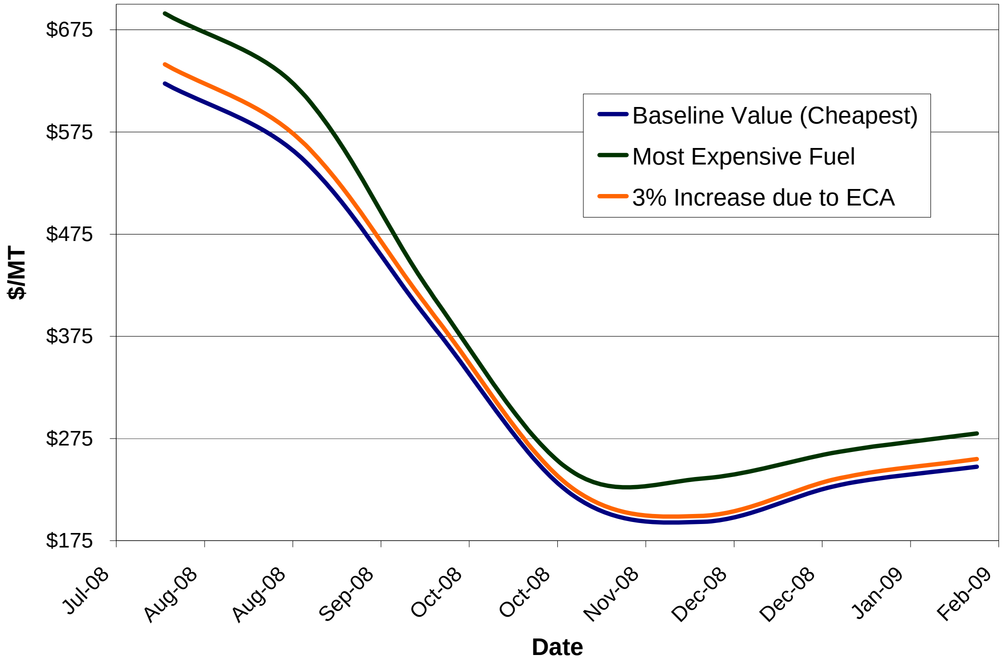

Figure 6.3-1 Range of Bunker Fuel Prices

This graph illustrates the price differential between these ports, comparing the estimated 3% ECA increase to the cheapest fuel for each month. We then plotted these calculated ECA increases (the 3% increases), the cheapest fuel (as a baseline) and the most expensive fuel for the same six month period. As can be observed from the previous calculations and the trends in Figure 1, there are both spatial and temporal price fluctuations in fuel prices. During this period (granted, a period of above-average fluctuations), the price of fuel varied both spatially and temporally. The variation over time is higher than the variation over ports; however, by either form of variation, the 3% increase in bunker fuel price due to the ECA is smaller than the normal price variation of the fuel.

6.3.4 Social Costs of the Proposed ECA and Distribution Across Stakeholders

The total social costs associated with complying with the Tier III NO_X limits and the ECA fuel sulfur limits for all ships operating in the U.S. portion of the proposed ECA are estimated to be the same as the total engineering costs presented in Chapter 5, or about $2.78 billion in 2020. For the reasons described above and explained more fully in the Appendix to this chapter, these costs are expected to be borne fully by consumers of international shipping services.

These social costs are small when compared to the total value of U.S. waterborne foreign trade. In 2007, waterborne trade for government and non-government shipments by vessel into and out of U.S. foreign trade zones, the 50 states, the District of Columbia, and Puerto Rico was about $1.4 trillion. Of that, about $1 trillion was for imports.[4]

Appendices

Appendix 6A

The methodology used in this Economic Impact Analysis (EIA) is rooted in applied microeconomic theory and was developed following U.S. EPA's recommended procedures.[5] This appendix describes the economic theory underlying the analysis and how it was applied to the problem of estimating the economic impacts of the proposed ECA on shipping engaged in international trade.

The Economic Theory Used to Estimate Economic Impacts

The approach used to estimate the economic impacts of the proposed ECA relies on the basic relationships between production and consumption in competitive markets.

Multi-Market, Partial-Equilibrium Approach

The approach is *behavioral* in that it builds on the engineering cost analysis by incorporating economic theory related to producer and consumer behavior to estimate changes in market conditions. As Bingham and Fox[6] note, this framework provides "a richer story" of the expected distribution of economic welfare changes across producers and consumers. In behavioral models, manufacturers of goods affected by a regulation are economic agents who can make adjustments, such as changing production rates or altering input mixes, which will generally affect the market environment in which they operate. As producers change their production levels in response to a new regulation, consumers of the affected goods are typically faced with changes in prices that cause them to alter the quantity that they are willing to purchase. These changes in price and output resulting from the market adjustments are used to estimate the distribution of social costs between consumers and producers.

This is also a *multi-market, partial equilibrium* approach. It is a multi-market approach in that more than one market is examined: the markets for marine engines, vessels, and international shipping transportation services. It is a partial-equilibrium approach in that rather than explicitly modeling all of the interactions in the global economy that are affected by international shipping, the individual markets that are directly affected by the ECA requirements are modeled in isolation. This technique has been referred to in the literature as "partial equilibrium analysis of multiple markets."[7]

This EIA does not examine the economic impact of the proposed ECA on finished goods that use ocean transportation services as inputs. This is because international shipping transportation services are only a small part of the total inputs of the final goods and services produced using the materials shipped. A change in the price of marine transportation services on the order anticipated by this program would not be expected to significantly affect the markets for the finished goods. So, for example, while we look at the impacts of the program on ocean transportation costs, we do not look at the impacts of the controls on gasoline produced using crude oil transported by ship, or on manufactured products that use petroleum products as inputs.

It should also be noted that this EIA estimates the aggregate economic impacts of the control program at the market level. This is not intended to be a firm-level analysis; therefore compliance costs facing any particular ship operator may be different from the market average, and the impacts of the program on particular firms can vary significantly. The difference can be important, particularly where the rule affects different firms' costs over different activity rates.

Competitive Markets

The methodology used in this EIA relies on an assumption of perfect competition. This means that consumers and firms are price takers and do not have the ability to influence market prices. Perfect competition is widely accepted for this type of analysis and only in rare cases are other approaches used.[8] Stopford's description of the shipping market and how prices are set in this market supports this assumption.[9]

In a perfectly competitive market at equilibrium with no externalities, the market price equals the value society (consumers) places on the marginal product, as well as the marginal cost to society (producers). Producers are price takers, in that they respond to the value that consumers put on the product. It should be noted that the perfect competition assumption is not primarily about the number of firms in a market. It is about how the market operates: whether or not individual firms have sufficient market power to influence the market price. Indicators that allow us to assume perfect competition include absence of barriers to entry, absence of strategic behavior among firms in the market, and product differentiation.[J,10] Finally, according to contestable market theory, oligopolies and even monopolies will behave very much like firms in a competitive market if it is possible to enter particular markets costlessly (i.e., there are no sunk costs associated with market entry or exit). This would be the case, for example, when products are substantially similar (e.g., a recreational vessel and a commercial vessel).

Intermediate-Run Impacts

This EIA explores economic impacts on affected markets in the intermediate run. In the intermediate run, some factors of production are fixed and some are variable. A short-run analysis, in contrast, imposes all compliance costs on producers, while a long-run analysis imposes all costs on consumers. The use of the intermediate run means that some factors of production are fixed and some are variable, and illustrates how costs will be shared between producers and consumers as the markets adjust to the new compliance program. The use of the intermediate time frame is consistent with economic practices for this type of analysis.

Short-Run Analysis

In the very short run, all factors of production are assumed to be fixed, leaving producers with no means to respond to the increased costs associated with the regulation (e.g., they cannot adjust labor or capital inputs). Within a very short time horizon, regulated producers are constrained in their ability to adjust inputs or outputs due to contractual, institutional, or other

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[J] The number of firms in a market is not a necessary condition for a perfectly competitive market. See Robert H. Frank, Microeconomics and Behavior, 1991, McGraw-Hill, Inc., p 333.

factors and can be represented by a vertical supply curve, as shown in Figure 6A-1. Under this time horizon, the impacts of the regulation fall entirely on the regulated entity. Producers incur the entire regulatory burden as a one-to-one reduction in their profit. This is referred to as the "full-cost absorption" scenario and is equivalent to the engineering cost estimates. Although there is no hard and fast rule for determining what length of time constitutes the very short run, it is inappropriate to use this time horizon for this type of analysis because it assumes economic entities have no flexibility to adjust factors of production. Note that the BAF is a way to avoid this scenario. Additionally, the fact that liner price schedules are renegotiated at least annually, and that individual service contracts may be negotiated more frequently, suggests that a very short-run analysis would not be suitable.

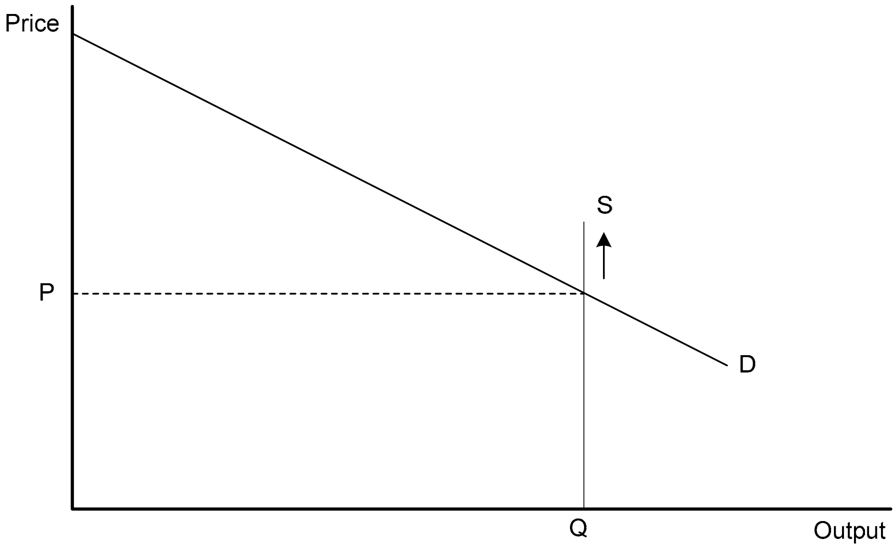


Figure 6A-1 Short-Run: All Costs Borne by Producers

Long-Run Analysis

In the long run, all factors of production are variable, and producers can be expected to adjust production plans in response to cost changes imposed by a regulation (e.g., using a different labor/capital mix). Figure 6A-2 illustrates a typical, if somewhat simplified, long-run industry supply function. The supply function is horizontal, indicating that the marginal and average costs of production are constant with respect to output. This horizontal slope reflects the fact that, under long-run constant returns to scale, technology and input prices ultimately determine the market price, not the level of output in the market.

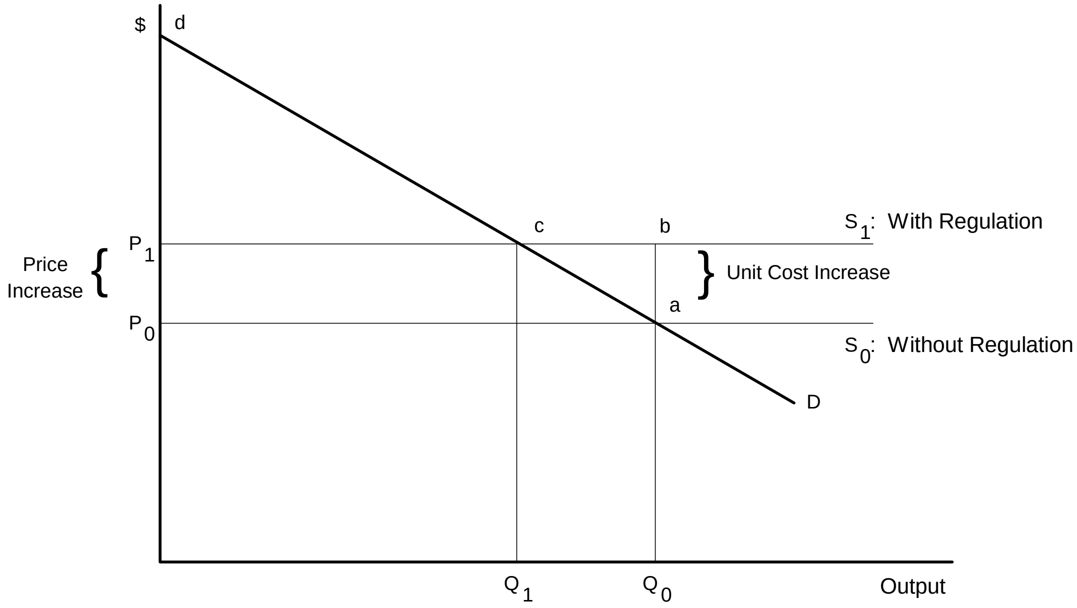


Figure 6A-2 Long-Run: Full Cost Pass-Through

Market demand is represented by the standard downward-sloping curve. The market is assumed here to be perfectly competitive; equilibrium is determined by the intersection of the supply and demand curves. In this case, the upward shift in the market supply curve represents the regulation's effect on production costs and is illustrated in Figure 6A-2. The shift causes the market price to increase by the full amount of the per-unit control cost (i.e., from P_0 to P_1). With the quantity demanded sensitive to price, the increase in market price leads to a reduction in output in the new with-regulation equilibrium (i.e., Q_0 to Q_1). As a result, consumers incur the entire regulatory burden as represented by the loss in consumer surplus (i.e., the area P_0ac P_1). In the nomenclature of EIAs, this long-run scenario is typically referred to as "full-cost pass-through."

Taken together, impacts modeled under the long-run/full-cost-pass-through scenario reveal an important point: under fairly general economic conditions, a regulation's impact on producers is transitory. Ultimately, the costs are passed on to consumers in the form of higher prices. However, this does not mean that the impacts of a regulation will have no impact on producers of goods and services affected by a regulation. For example, the long run may cover the time taken to retire today's entire capital equipment, which could take decades. Therefore, transitory impacts could be protracted and could dominate long-run impacts in terms of present value. In addition, to evaluate impacts on current producers, the long-run approach is not appropriate. Consequently a time horizon that falls between the very short-run/full-cost-absorption case and the long-run/full-cost-pass-through case is most appropriate for this EIA.

Intermediate Run Analysis

The intermediate run time frame allows examination of impacts of a regulatory program during the transition between the very short run and the long run. In the intermediate run, there is some resource immobility which may cause producers to suffer producer surplus losses. Specifically, producers may be able to adjust some, but not all, factors of production, and they therefore will bear some portion of the costs of the regulatory program. The existence of fixed production factors generally leads to diminishing returns to those fixed factors. This typically manifests itself in the form of a marginal cost (supply) function that rises with the output rate, as shown in Figure 6A-3.

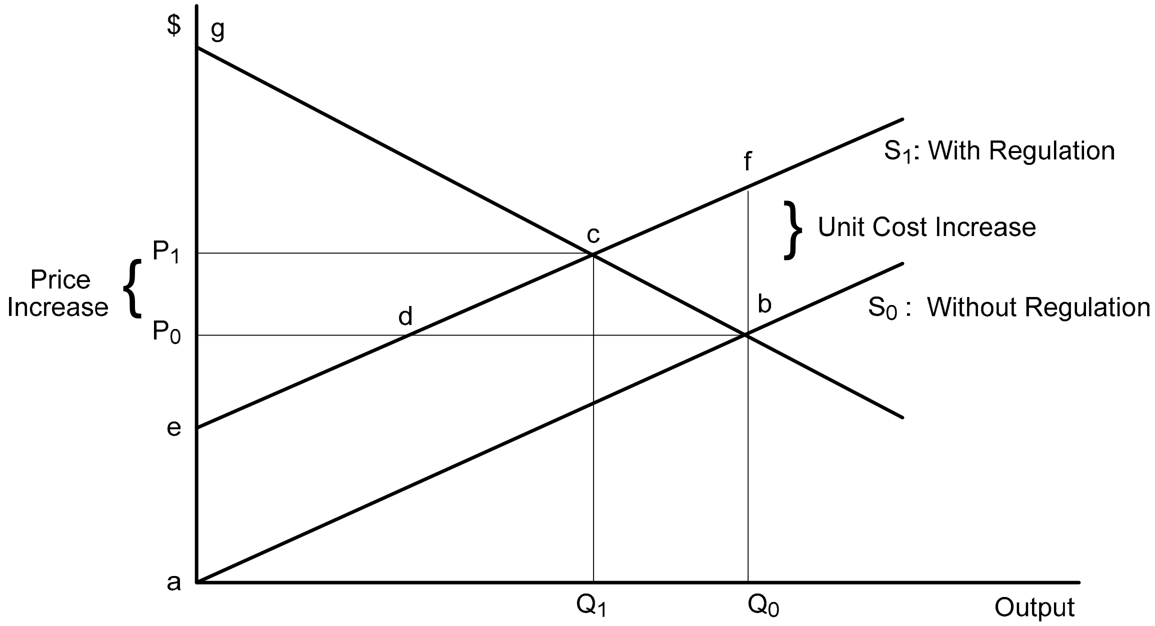
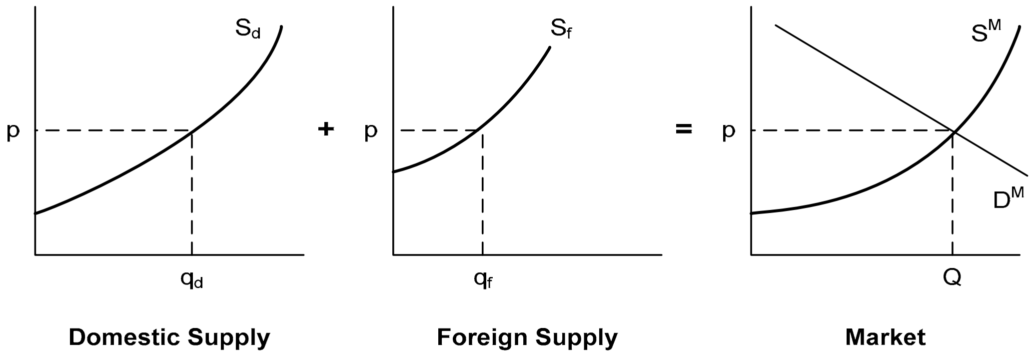


Figure 6A-3 Intermediate-Run: Partial-Cost Pass-Through

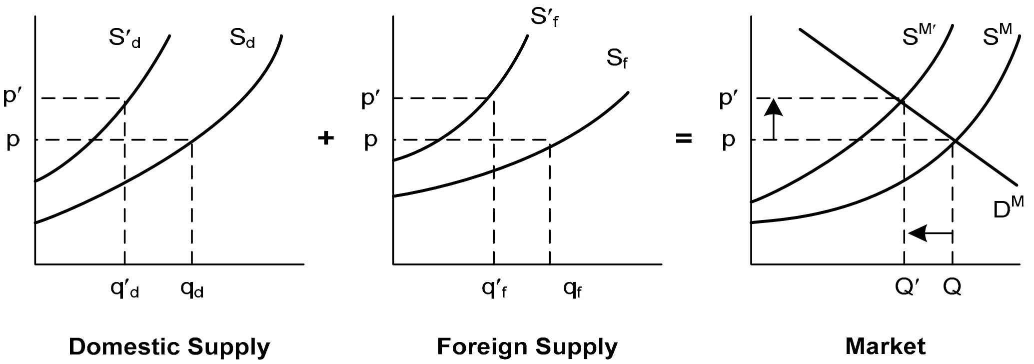
Again, the regulation causes an upward shift in the supply function. The lack of resource mobility may cause producers to suffer profit (producer surplus) losses in the face of regulation; however, producers are able to pass through some of the associated costs to consumers, to the extent the market will allow. As shown, in this case, the market-clearing process generates an increase in price (from P_0 to P_1) that is less than the per-unit increase in costs, so that the regulatory burden is shared by producers (net reduction in profits) and consumers (rise in price). In other words, there is a loss of both producer and consumer surplus.

Economic Impacts of a Control Program – Single Market

A graphical representation of a general economic competitive model of price formation, as shown in Figure 6A-4(a), posits that market prices and quantities are determined by the intersection of the market supply and market demand curves. Under the baseline scenario, a market price and quantity (p,Q) are determined by the intersection of the downward-sloping market demand curve (D^M) and the upward-sloping market supply curve (S^M). The market supply curve reflects the sum of the domestic (S_d) and import (S_f) supply curves.



a) Baseline Equilibrium



b) With-Regulation Equilibrium

Figure 6A-4 Market Equilibrium Without and With Regulation

With the regulation, the costs of production increase for suppliers. The imposition of these regulatory control costs is represented as an upward shift in the supply curve for domestic and import supply by the estimated compliance costs. As a result of the upward shift in the supply curve, the market supply curve will also shift upward as shown in Figure 6A-4(b) to reflect the increased costs of production.

At baseline without the new standards, the industry produces total output, Q, at price, p, with domestic producers supplying the amount q_d and imports accounting for Q minus q_d, or q_f. With the regulation, the market price increases from p to p′, and market output (as determined from the market demand curve) decreases from Q to Q′. This reduction in market output is the net result of reductions in domestic and import supply.

As indicated in Figure 6A-4, when the new standards are applied the supply curve will shift upward by the amount of the estimated compliance costs. The demand curve, however, does not shift in this analysis. This is explained by the dynamics underlying the demand curve. The demand curve represents the relationship between prices and quantity demanded. Changes in prices lead to changes in the quantity demanded and are illustrated by *movements along* a constant demand curve. In contrast, changes in consumer tastes, income, prices of related goods, or population would lead to change in demand and are illustrated as *shifts* in the position of the demand curve.[K,11] For example, an increase in the number of consumers in a market would cause the demand curve to shift outward because there are more individuals willing to buy the good at every price. Similarly, an exogenous increase in average income would also lead the demand curve to shift outward or inward, depending on whether people choose to buy more or less of a good at a given price.

Economic Impacts of a Control Program – Multiple Markets

The above description is typical of the expected market effects for a single product market considered in isolation (for example, the ocean transportation service market). However, the markets considered in this EIA are more complicated because they are linked: the market for engines is affected by the market for vessels, which is affected by the market for international marine transportation services. In particular, it is reasonable to assume that the input-output relationship between the marine diesel engines and vessels is strictly fixed and that the demand for engines varies directly with the demand for vessels. Similarly, the demand for vessels varies directly with the demand for marine transportation services. A demand curve specified in terms of its downstream consumption is referred to as a derived demand curve. Figure 6A-5 illustrates how a derived demand curve is identified.

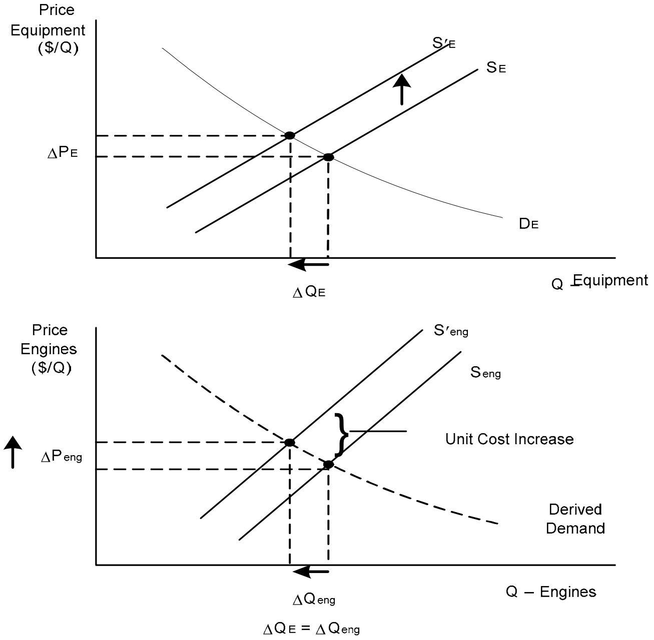


Figure 6A-5 Derived-Demand Curve for Engines

[K] An accessible detailed discussion of these concepts can be found in chapters 5-7 of Nicholson’s (1998) intermediate microeconomics textbook.

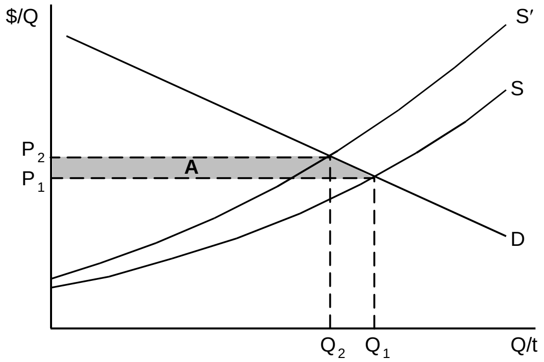
Consider an event in the engine market, such as a new technology requirement, that causes the price of an engine to increase by ΔP_{eng}. This increase in the price of an engine will cause the supply curve in the engine market to shift up, leading to a decreased quantity (ΔQ_{eng}). The change in engine production leads to a decrease in the demand for equipment (ΔQ_E). The difference between the supply curves in the equipment market, $S'_E - S_E$, is the difference in price in the engine market, ΔP_{eng}, at each quantity. Note that the supply and demand curves in the equipment market are needed to identify the derived demand in the engine market.

In the market for vessels and engines, the derived demand curves are expected to be vertical. The full costs of the engines will be passed into the cost of vessels, and the cost of vessels will be passed into the cost of ocean transportation.

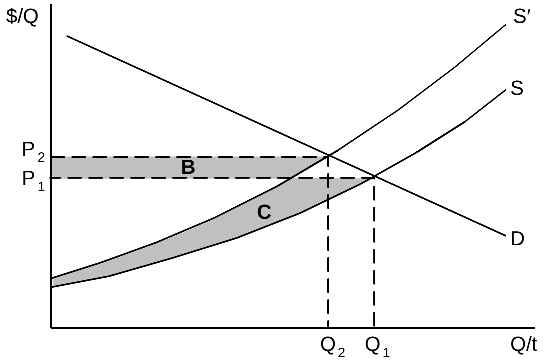
Using Economic Theory to Estimate the Social Costs of a Control Program

The economic welfare implications of the market price and output changes with the regulation can be examined by calculating consumer and producer net “surplus” changes associated with these adjustments. This is a measure of the negative impact of an environmental policy change and is commonly referred to as the “social cost” of a regulation. It is important to emphasize that this measure does not include the benefits that occur outside of the market, that is, the value of the reduced levels of air pollution with the regulation. Including this benefit will reduce the net cost of the regulation and even make it positive.

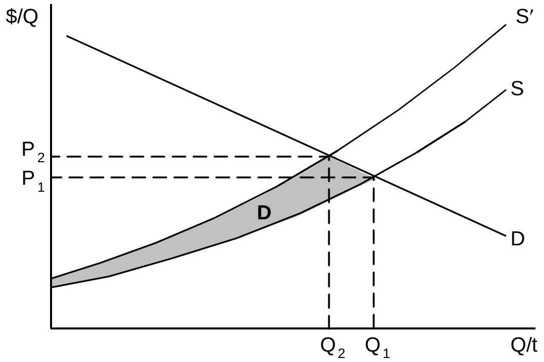
The demand and supply curves that are used to project market price and quantity impacts can be used to estimate the change in consumer, producer, and total surplus or social cost of the regulation (see Figure 6A-6).



(a) Change in Consumer Surplus with Regulation



(b) Change in Producer Surplus with Regulation



(c) Net Change in Economic Welfare with Regulation

Figure 6A-6 Economic Welfare Calculations: Changes in Consumer, Producer, and Total Surplus

The difference between the maximum price consumers are willing to pay for a good and the price they actually pay is referred to as "consumer surplus." Consumer surplus is measured as the area under the demand curve and above the price of the product. Similarly, the difference between the minimum price producers are willing to accept for a good and the price they actually receive is referred to as "producer surplus." Producer surplus is measured as the area above the supply curve below the price of the product. These areas can be thought of as consumers' net benefits of consumption and producers' net benefits of production, respectively.

In Figure 6A-6, baseline equilibrium occurs at the intersection of the demand curve, D, and supply curve, S. Price is P_l with quantity Q_l. The increased cost of production with the regulation will cause the market supply curve to shift upward to S′. The new equilibrium price of the product is P_2. With a higher price for the product there is less consumer welfare, all else being unchanged. In Figure 6A-6(a), area A represents the dollar value of the annual net loss in consumer welfare associated with the increased price. The rectangular portion represents the loss in consumer surplus on the quantity still consumed due to the price increase, Q_2, while the triangular area represents the foregone surplus resulting from the reduced quantity consumed, $Q_l – Q_2$.

In addition to the changes in consumers' welfare, there are also changes in producers' welfare with the regulatory action. With the increase in market price, producers receive higher revenues on the quantity still purchased, Q_2. In Figure 6A-6(b), area B represents the increase in revenues due to this increase in price. The difference in the area under the supply curve up to the original market price, area C, measures the loss in producer surplus, which includes the loss associated with the quantity no longer produced. The net change in producers' welfare is represented by area B – C.

The change in economic welfare attributable to the compliance costs of the regulations is the sum of consumer and producer surplus changes, that is, –(A) + (B–C). Figure 6A-6(c) shows the net (negative) change in economic welfare associated with the regulation as area D.

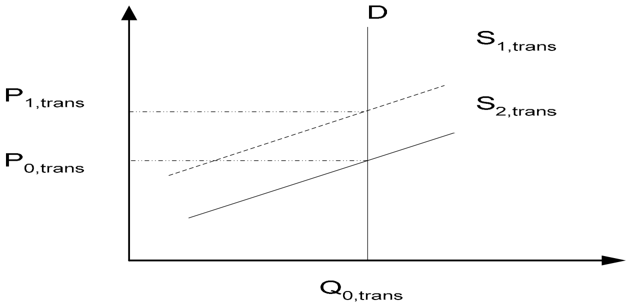
How the Economic Theory Applied in This EIA

In the above explanation of how to estimate the market and social welfare impacts of a control action, the price elasticities of supply and demand were nonzero. This was reflected in the upward-slope of the supply curve and the downward slope of the demand curve. In the derived demand analysis, a nonzero price elasticity of demand in the vessel market yielded a nonzero price elasticity of demand in the engine market.

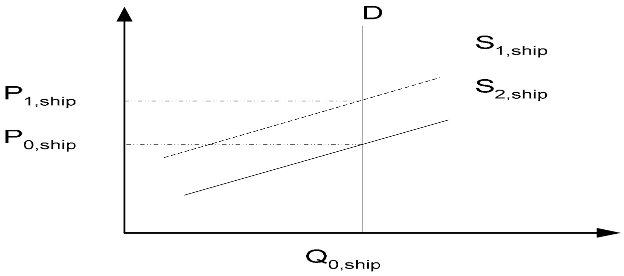
However, the price elasticity of demand in the international shipping market is expected to be nearly perfectly inelastic (demand curve with near-infinite slope – a vertical demand curve). This is not to say that an increase in price has no impact on quantity demanded; rather, it means that the price increase would have to be very large before there is a noticeable change in quantity demanded.

The price elasticity of demand is expected to be near perfectly inelastic because there are no reasonable alternatives to shipping by vessel for the vast majority of products transported by sea to the United States and Canada. It is impossible to ship goods between these countries and Asia, Africa, or Europe by rail or highway. Transportation of goods between these countries and Central and South America by rail or highway would be inefficient due to the time and costs involved. As a result, over 90% of the world's traded goods are currently transported by sea.[12] While aviation may be an alternative for some goods, it is impossible for goods shipped in bulk or goods shipped in large quantities. There are also capacity constraints associated with trans-continental aviation transportation, and the costs are higher on a per tonne basis.

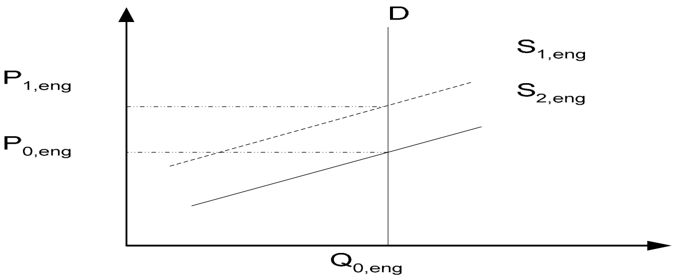
A nearly perfectly inelastic price elasticity of demand simplifies the analysis described above. Figure 6A-7 reproduces the relationships in a multi-level market but this time with a nearly perfectly inelastic demand curve in the international shipping market. The relationships between this market and the markets for vessels and engines means that the derived demand curves for engines and vessels are also expected to be nearly perfectly inelastic. Specifically, if demand for transportation services is not expected to be affected by a change in price, then the demand for vessels will also remain constant, as will the demand for engines.



(a) The vertical demand curve for ocean transportation market



(b) The vertical demand curve for ocean vessel market



(c) The vertical demand curve for C-3 engine market

Figure 6A-7 Market Impacts in Markets with Nearly Perfectly Inelastic Demand

As indicated in Figure 6A-7, a change in unit production costs due to compliance with the engine emission and fuel sulfur requirements in the proposed ECA shifts the supply curves for engines, vessels, and ocean transportation services. The cost increase causes the market price to increase by the *full* amount of per unit control cost (i.e. from P_0 to P_1) while the quantity demanded for engines, vessels, and transportation services remains constant. Thus, engine manufacturers are expected to be able to pass on the full cost of producing Tier III compliant engines to the vessel builders, who are expected to be able to pass the full cost of installing the engines and fuel switching equipment on to the vessel owners. The vessel owners, in turn, are expected to be able to pass on these cost increases, as well as the additional operating costs they incur for the use of SCR reductant (urea) and low sulfur fuel while operating in the ECA.

Note that the fuel and urea costs affect the ocean transportation services market directly, but affect the vessel and engine markets only through the derived demand curves. That is, the equilibrium prices and quantities for vessels and engines will change only if the quantity of ocean transportation services demanded changes due to fuel and urea costs. Because the changes in fuel and urea prices are expected to be too small to affect the quantity of ocean transportation services demanded, the markets for vessels and engines are not expected to be affected by fuel changes.

The sole exception for the assumption of nearly perfectly price elasticity of demand is the cruise market. Clearly, the consumers in that market, tourists and holiday-makers, have alternatives available for their recreational activities. If the cost of a cruise increases too much, they may decide to spend their vacation in other activities closer to home, or may elect to fly somewhere instead. As a result, the costs of compliance for the cruise industry are more likely to be shared among stakeholders. If the price elasticity of demand is larger (in absolute value) than the price elasticity of supply, ship owners will bear a larger share of the costs of the program; if the price elasticity of demand is smaller (in absolute value) than the price elasticity of supply, consumers will bear a larger share of the program. Similarly, the vessel builders and engine manufacturers will also bear a portion of the costs. If the quantity demanded for cruises decreases, the derived quantity demanded for vessels will decrease, as will the derived quantity demanded for engines. If the supply curves for these industries are not perfectly elastic (i.e., horizontal), then the downward-sloping derived demand curves will lead to shared impacts among the sectors.

As described in section 6.3.3 of this chapter, the impacts on the cruise market are expected to be small, with total engine and vessel costs increasing about one percent and operating costs increasing between 1.5 and 6 percent. These increases are within the range of historic variations in bunker fuel prices. The impact on the cruise market, then, may be similar in effect to the market's response to those changes.

Finally, it may be possible for cruise ships to offset some of these costs by advertising the environmental benefits of using engines and fuels that comply with the ECA requirements. Many cruise passengers enjoy this form of recreational because it allows them a personal-level experience with the marine environment, and they may be willing to pay an increased fee to protect that nature. If people prefer more environmentally friendly cruises, then the demand curve for these cruises will shift up. Consumers will be willing to bear more of the costs of the changes. If the demand shift for environmentally friendly cruises is large enough, both the equilibrium price and quantity of cruises might increase.

Appendix 6B

Estimation of Transportation Market Impacts

The U.S. and Canada have submitted a joint proposal to IMO to designate an emission control area in which ships would need to comply with stringent fuel sulfur limits and Tier III NO_X standards. To characterize the increase in vessel operating costs due to the proposed ECA, and therefore the impacts on transportation market prices, calculations were performed for three types of ocean going vessels, container, bulk carrier, and cruise liner. Our estimates were developed using typical vessel characteristics, projected fuel and urea costs, and worst case sea-route data. This appendix presents the methodology used for these calculations.

Container Vessel

A typical container vessel was derived using data obtained from the Lloyd's of London Sea-Web Database. This data base includes information on actual vessel size (Dead Weight Tonnes (DWT)) and engine power (kilowatt – hour (kW-hr)) for a wide range of vessel types.

Operating costs included those associated with switching from residual fuel to 0.1% sulfur distillate fuel and urea consumption for vessels equipped with selective catalytic reduction (SCR). The fuel and urea costs are based on projections that are presented in the ECA proposal. These fuel costs estimates are $322/tonne for residual fuel and $468/tonne for 0.1% sulfur distillate fuel. We use a urea consumption rate of 7.5% of fuel consumption, at $1.52/gallon.

To develop a representative sea-route for our price estimations, we created a 'circle route' for a theoretical trip. Since the Port of Los Angeles[13], one of the largest ports in the U.S., lists the majority of its cargo as traveling from South Asia, our route had a vessel hypothetically travel from Singapore to the Port of Seattle, then down the West Coast of the United States (U.S.) to the Port of Los Angeles, then back to Singapore. To map this route, we divided it into three "legs." The first leg has the vessel traveling from Singapore to the Port of Seattle; the second part travels down the West Coast of the U.S. to the Port of Los Angeles/Long Beach (POLA/LB); the third leg continues from Los Angeles to Singapore. The total distance for this route was determined from http://nauticaldistance.com/, and is described below.

We understand that it will take some additional time and distance to switch vessel operations from one fuel to another. Additionally, we acknowledge that vessels may enter the ECA at an angle relative to the port in question, and would be operating in the ECA for a slightly longer distance than the 200 nautical miles of the ECA. Therefore, to make our fuel usage estimates as accurate as possible, we included some additional ECA traversing distances in our circle route calculations, adding 183 nm to the distance for reaching the Port of Seattle, and 35 nm to the distance from POLA/LB.

Baseline Operating Costs

In order to begin our estimated fuel cost increases, we needed to establish the fuel usage and prices for our baseline route (i.e. the price of the route operating on residual fuel). We determined average operational values for our hypothetical vessel by selecting the mid-point of the operational ranges used today by OGV. Therefore, our baseline estimations for the fuel usage for the first leg were determined by multiplying the engine power for the average sized containership (in kilowatts (kW)) by the average estimated engine efficiency (80 percent) as well as the average residual fuel consumption (195 grams fuel per kilowatt hour (g/kW-hr)). (Equation 6B-1) This value was then multiplied by the nautical miles (nm) for the first leg of the trip (the distance from Singapore to Seattle (7,064 nm)), and divided by the average engine speed (16 knots). To obtain the correct units for the calculation, a unit conversion was also included. (Equation 6B-2) As average values are represented here, it is possible that these values could fluctuate slightly depending on the vessel's speed, engine efficiency, and specific fuel consumption, but we believe that these estimates provide a reasonable forecast for the majority of container vessels in operation today.

Equation 6B-1

$$36{,}540kW \times 0.8 \times 195\, {}^{g_{resid}}\!/_{kW-hr} = 5{,}700{,}240\, {}^{g_{resid}}\!/_{hr}$$

Equation 6B-2

$$\frac{5{,}700{,}240\, {}^{g_{resid}}\!/_{hr} \times 7{,}064nm}{16\, {}^{knots}\!/_{hr}} \times \frac{tonne}{1{,}000{,}000g} = 2{,}517 tonne_{resid}$$

The same determinations were conducted for the second leg of the trip (1,143 nm, Equation 6B-3) and the third leg (7,669 nm, Equation 6B-4).

Equation 6B-3

$$\frac{5{,}700{,}240\, {}^{g_{resid}}\!/_{hr} \times 1{,}143nm}{16\, {}^{knots}\!/_{hr}} \times \frac{tonne}{1{,}000{,}000g} = 407 tonne_{resid}$$

Equation 6B-4

$$\frac{5{,}700{,}240\, {}^{g_{resid}}\!/_{hr} \times 7{,}669nm}{16\, {}^{knots}\!/_{hr}} \times \frac{tonne}{1{,}000{,}000g} = 2{,}732 tonne_{resid}$$

Total fuel usage for each leg of the trip was multiplied by the price of the fuel (2006 U.S. dollars per tonne ($/tonne) which provided the baseline cost of fuel for each leg. These costs were then summed to produce an aggregate estimation of fuel cost for the entire circle trip (Equation 6B-5). This calculation provides the baseline cost of about $1.8M for an average sized container ship to traverse the theoretical circle route.

Equation 6B-5

$$(2{,}517 tonne_{resid} + 407 tonne_{resid} + 2{,}732 tonne_{resid}) \times \$322.48 / tonne_{resid} = \$1{,}823{,}947$$

Operating Costs with an ECA

Operating cost increases due to an ECA are due to increased fuel costs and urea consumption within the ECA. Operating costs are assumed to remain unchanged outside the ECA. In addition, the ECA is assumed to have no impact on the route travelled.

Increased Fuel Costs

To determine the fuel usage and price increase caused by the ECA on our vessel traveling our theoretical circle route, we conducted the same analysis as our baseline using the appropriate distillate fuel properties. Since the distillate fuel will most likely only be used in the ECA, the remainder of the trip will continue operating on residual fuel. Therefore, we adjusted our trip section distances accordingly, using residual fuel over the first leg for 6,679 nm and over 7,434 nm for the third leg, while the remainder of the trip was determined using a distillate fuel. Equation 6B-6 provides the approximation for engine power and fuel consumption using distillate fuel and Equation 6B-7, 8, and 9 calculate the corresponding trip segment fuel usages. Due to the chemical properties of the two marine fuels, there is approximately a five percent (5%) increase in energy, on a mass basis, when operating on the distillate fuel instead of the residual fuel, and this increase is accounted for in Equation 6B-6.

Equation 6B-6

$$36{,}540kW \times 0.8 \times \frac{195\,{}^{g_{distil}}\!/_{kW-hr}}{1+0.05} = 5{,}428{,}800\,{}^{g_{distil}}\!/_{hr}$$

Equation 6B-7a Residual Fuel Estimation

$$\frac{5{,}700{,}240\,{}^{g_{resid}}\!/_{hr} \times 6{,}679nm}{16\,{}^{knots}\!/_{hr}} \times \frac{tonne}{1{,}000{,}000g} = 2{,}379tonne_{resid}$$

Equation 6B-7b Distillate Fuel Estimation

$$\frac{5{,}428{,}800\,{}^{g_{distil}}\!/_{hr} \times 385nm}{16\,{}^{knots}\!/_{hr}} \times \frac{tonne}{1{,}000{,}000g} = 131tonne_{distil}$$

Equation 6B-8

$$\frac{5{,}428{,}800\,{}^{g_{distil}}\!/_{hr} \times 1{,}143nm}{16\,{}^{knots}\!/_{hr}} \times \frac{tonne}{1{,}000{,}000g} = 388tonne_{distil}$$

Equation 6B-9a Residual Fuel Estimation

$$\frac{5{,}700{,}240\,{}^{g_{resid}}\!/_{hr} \times 7{,}434knots}{16\,{}^{knots}\!/_{hr}} \times \frac{tonne}{1{,}000{,}000g} = 2{,}648tonne_{resid}$$

Equation 6B-9b Distillate Fuel Estimation

$$\frac{5{,}428{,}800\,{}^{g_{distil}}\!/_{hr} \times 235nm}{16\,{}^{knots}\!/_{hr}} \times \frac{tonne}{1{,}000{,}000g} = 80tonne_{distil}$$

Urea Costs

Switching to a distillate marine fuel will achieve reductions only in sulfur and particulate emissions. In order to meet the required Nitrogen Oxides (NO_X) emission reductions, vessel owners/operators would need to install a Selective Catalytic Reduction (SCR) device, or similar technologies, on new vessels built in 2016 and later. Using an SCR requires dosing exhaust gases with urea to aid with the emission reductions – which adds some additional costs to the operation of the vessel. In an SCR on a marine engine, the average dosage of urea is seven and a half percent (7.5%) per gallon of distillate fuel used. Subsequently, to estimate the volume of urea required for our circle route, we multiplied the distillate quantity determined above by this urea percentage. (Equation 6B-10) As we expect these costs to be incurred several years in the future, we used the analysis preformed for the EPA by EnSys[14] which predicted that in 2020, 33.2% of the fuel used in ECAs will be on vessels equipped SCR. The urea costs below are adjusted to reflect this prediction.

Equation 6B-10

$$599 tonnes_{distil} \times \frac{kg}{0.001 tonne} \times \frac{m^3}{836.6 kg_{distil}} \times \frac{264.17 gal}{m^3} \times 0.075 = 14{,}185 gal_{urea} \times 0.332 = 4{,}709 gal_{urea}$$

To determine the additional price of our vessel's operation through the ECA, we then multiplied the fuel and urea quantities by their corresponding prices ($322.48/tonne for residual, $467.92/tonne for distillate, and $1.52/gal for the urea). We then summed these values to determine the aggregate price for fuel and urea required for our container vessel to travel our circle route with the proposed ECA in place (Equation 6B-11).

Equation 6B-11

$$\begin{aligned}&[(2{,}379 tonne_{resid} + 2{,}648 tonne_{resid}) \times \$322.48 / tonne_{resid}] + \\ &[(131 tonne_{distil} + 388 tonne_{distil} + 80 tonne_{distil}) \times \$467.92 / tonne_{distil}] + \\ &(4{,}709 gal_{urea} \times \$1.52 / gal_{urea}) = \$1{,}908{,}549_{ECA}\end{aligned}$$

The total estimated price for an average sized containership traversing the circle with the ECA in place is just over $1.9M. The cost increase of this trip caused by the fuel and urea prices used in the ECA came from subtracting the baseline (residual fuel) trip price from the ECA price (Equation 6B-12). The price differential between the baseline trip and the ECA trip is demonstrated in Equation 6B-13 and takes into consideration the fuel cost portion of the operational cost for a vessel, which is typically around 60 percent of the total. As can be seen, by operating in the ECA for our theoretical circle route it is estimated that the operational costs due to the distillate fuel is approximately three percent (3%).

Equation 6B-12

$$\$1{,}908{,}549_{ECA} - \$1{,}823{,}947_{baseline} = \$84{,}602$$

Equation 6B-13

$$0.60 \times \frac{\$1{,}908{,}549_{ECA} - \$1{,}823{,}947_{baseline}}{\$1{,}823{,}947_{baseline}} \times 100 = 2.8\%$$

To put this price increase in some perspective, we assumed our average sized containership was hauling goods, such Twenty-foot Equivalent Units (TEU), and estimated the increase per each TEU. Estimating these prices required the cargo weight of the vessel. Literature shows that approximately 93-97% of a container vessel's DWT is used for hauling cargo, with the remaining weight composing the crew, vessel engines and hull, and fuel[15]. Equation 6B-14 shows the calculation used to convert the vessel's DWT to cargo weight using the middle value of 95%.

Equation 6B-14

$$50{,}814 DWT \times 0.95 = 48{,}273 c\arg o\_tonnes$$

Dividing the difference between the baseline fuel price and the ECA fuel price we calculated previously by the cargo tonnes as established in Equation 6B-14 provided the price increase per tonne of good shipped for the entire route (Equation 6B-15).

Equation 6B-15

$$\frac{(\$1{,}908{,}549_{ECA} - \$1{,}823{,}947_{baseline})}{48{,}273 c\arg o\_tonnes} = \$1.75 / c\arg o\_tonne_{increase}$$

Using this value and the weight of a full TEU (10 metric tonnes)[16], we determined the cost increase for shipping a fully loaded TEU across our circle route (Equation 6B-16).

Equation 6B-16

$$\frac{\$1.75}{c\arg o\_tonne_{increase}} \times \frac{10 tonnes}{full\_TEU} = \$17.53 / \ full\_TEU_{increase}$$

Bulk Carrier

Since the majority of goods transported to the U.S. are brought by bulk carriers as well as container vessels, and bulk carriers are of a different construction than container vessels, we also conducted estimations as to what the price increase per tonne of bulk cargo would be due to the ECA. For a comparison, we calculated what the price increase would be for a tonne of bulk cargo carried on a vessel traversing the same theoretical circle route as the containership.

Equation 6B-17 shows the same calculations as performed above for the containership using the average engine power for a bulk carrier (3,825 kW) and the total trip distance (15,876 nm)

Equation 6B-17

$$\frac{3{,}825 kW \times 0.8 \times 195 \, {}^{g_{resid}}\!/\!_{kW-hr} \times 15{,}876 nm}{16 \, {}^{knots}\!/\!_{hr}} \times \frac{tonne}{1{,}000{,}000 g} = 592 tonne_{resid}$$

This determination was also conducted for the ECA, using the appropriate values for the distillate part of the circle route (1,763 nm) and the residual fuel part of the route (14,113 nm) (Equation 6B-18 and 19 respectively). Equation 6B-20 determines the urea required for use in the ECA (as was established in Equation 6B-10), and Equation 6B-21 estimates the overall price increase for the bulk carrier if it was to operate on the theoretical circle route through the ECA.

Equation 6B-18

$$3{,}825kW \times 0.8 \times \frac{195\, {}^{g_{resid}}\!\!/\!_{kW-hr}}{1+0.05} \times \frac{1{,}763nm}{16\, {}^{knots}\!/\!_{hr}} \times \frac{tonne}{1{,}000{,}000g} = 62.6tonne_{distil}$$

Equation 6B-19

$$\frac{3{,}825kW \times 0.8 \times 195\, {}^{g_{resid}}\!\!/\!_{kW-hr} \times 14{,}113nm}{16\, {}^{knots}\!/\!_{hr}} \times \frac{tonne}{1{,}000{,}000g} = 526tonne_{resid}$$

Equation 6B-20

$$62.6tonnes_{distil} \times \frac{kg}{0.001tonne} \times \frac{m^3}{836.6kg_{distil}} \times \frac{264.17gal}{m^3} \times 0.075 = 1{,}483gal_{urea} \times 0.332 = 492gal_{urea}$$

Equation 6B-21

$$\begin{aligned}&[(62.6tonne_{distil} \times \$467.92/tonne_{distil}) + (526tonne_{resid} \times \$322.48/tonne_{resid}) + (492gal_{urea} \times \$1.52/gal_{urea})]\\ &-[592tonne_{resid} \times \$322.48/tonne_{resid}] = \$8{,}756_{increase}\end{aligned}$$

To establish this price increase in terms of bulk cargo shipped, the value from Equation 6B-21 was divided by the available cargo weight for the bulk carrier which was determined from the actual vessel weight (16,600 tonnes) as was performed in Equation 6B-14. (Equation 6B-22)

Equation 6B-22

$$\frac{\$8{,}756_{increase}}{(16{,}600bulk\_c\arg o\_tonnes \times 0.95)} = \$0.56/bulk\_c\arg o\_tonne_{increase}$$

As can be seen, for an average bulk carrier that would travel from Singapore to Seattle, LA/LB, and then back out to Singapore, the price increase caused by operation in the ECA would be around $0.56 per tonne of good shipped. As with the other vessels, this price would fluctuate depending on the distance traveled within the ECA, the vessel's speed, and the engine power used.

Cruise Ship

We also conducted an analysis on a typical Alaskan cruise liner. These vessels tend to operate close to shore and would be within the ECA for the majority of their routes. As such, this analysis presents worst case cost impacts for this type of vessel.

To conduct this analysis, a series of average vessel characteristics were chosen along with a typical 7 day Alaskan cruise route. The characteristics used below are the main engine power (31,500 kW), auxiliary engine power (18,680 kW), base specific residual fuel consumption (178 g_{fuel}/kW-hr for main engines, 188 g_{fuel}/kW-hr for auxiliary engines), distance between voyage destinations (5 destinations with a distance ranging between 230 to 700 nm), maximum vessel speed (21.5 knots), and the average number of passengers on-board the vessel (1,886 people).

Additionally, the arrival and departure times at the various ports of call along the cruise route were used to calculate the average speed travelled between each destination. The required power for a given journey segment was calculated using the relationship shown in Equation 6B-23. This relationship was developed for the "2005-2006 BC Ocean-Going Vessel Emissions Inventory"[17] and was shared with several cruise ship operators for their input and validation.

Equation 6B-23

$$\text{Required engine power} = 0.8199 \times (\text{avg speed/max speed})^3 - 0.0191 \times (\text{avg speed/max speed})^2 \\ + 0.0297 \times (\text{avg speed/max speed}) + 0.1682$$

This relationship was developed to approximate effective power given cruise ships' diesel-electric operation. The auxiliary engines reported within the Lloyd's of London 'Seaweb' database[18], and are presumably operated independently of the vessels main diesel-electric power generation, as well as assumed to operate at an average of 50% power for the entire voyage.

To demonstrate the price increase for the cruise liner that would operate within the ECA, calculations for one leg of the Alaskan voyage are shown in Equation 6B-24-27, the entire trip operational cost increase per person in Equation 6B-28, and with Table 6B-1 depicting the total increases over the entire trip broken out by destination.

Equation 6B-24

$$31{,}500kW \times 0.5683 \times \frac{178g_{fuel}}{kW - hr} \times 704knots \times \frac{hr}{16.76knots} \times \frac{tonne}{1{,}000{,}000g} = 134tonne_{resid}$$

Equation 6B-25

$$\frac{134tonne_{resid}}{1{,}886people} \times \frac{\$322.48}{tonne_{resid}} = \$22.89 / person_{resid}$$

Equation 6B-26

$$31{,}500kW \times 0.5683 \times \frac{178g_{fuel}}{(1.05)kW - hr} \times 704knots \times \frac{hr}{16.76knots} \times \frac{tonne}{1{,}000{,}000g} = 127tonne_{distil}$$

Equation 6B-27

$$\frac{127tonne_{distil}}{1{,}886people} \times \frac{\$467.92}{tonne_{distil}} = \$31.62 / person_{distil}$$

Equation 6B-28

$$\$31.62 - \$22.89 = \$8.73 / person_{main\_increase}$$

Table 6B-1 Alaskan Cruise Liner Destinations and the Corresponding Operational Price Increases

DESTINATION ORIGIN	**DESTINATION CONCLUSION**	**ESTIMATED PRICE INCREASE / PERSON ($)**
Vancouver	Sitka	$8.73
Sitka	Hubbard Glacier	$3.06
Hubbard Glacier	Juneau	$2.67
Juneau	Ketchilkan	$2.42
Ketchilkan	Vancouver	$6.13
Total		**23.02_{\text{main_increase}}$**

Additionally, the operational cost increases for the auxiliary engines were estimated (Equation 6B-29-33), as well as the cost increases caused by dosing the engine exhaust with urea (Equation 6B-34& 35), and the total price increase for the cruise (Equation 6B-36) divided by the length of the cruise (Equation 6B-37).

Equation 6B-29

$$18{,}680kW \times 0.50 \times \frac{188g_{fuel}}{kW - hr} \times 168hrs \times \frac{tonne}{1{,}000{,}000g} = 295tonne_{resid}$$

Equation 6B-30

$$\frac{295tonne_{resid}}{1{,}886\,people} \times \frac{\$322.48}{tonne_{resid}} = \$50.44 / person_{resid}$$

Equation 6B-31

$$18{,}680kW \times 0.50 \times \frac{188g_{fuel}}{(1.05)kW - hr} \times 168hrs \times \frac{tonne}{1{,}000{,}000g} = 281tonne_{distil}$$

Equation 6B-32

$$\frac{281tonne_{distil}}{1{,}886\,people} \times \frac{\$467.92}{tonne_{distil}} = \$69.71 / person_{distil}$$

Equation 6B 33

$$\$69.71 - \$50.44 = \$19.27 / person_{aux\_increase}$$

Equation 6B-34

$$616.75tonnes_{distil} \times \frac{kg}{0.001tonne} \times \frac{m^3}{836.6kg_{distil}} \times \frac{264.17gal}{m^3} \times 0.075 = 14{,}606gal_{urea} \times 0.332 = 4{,}849gal_{urea}$$

Equation 6B-35

$$\frac{4{,}849gal_{urea}}{1{,}886\,people} \times \$1.52 / gal_{urea} = \$3.91_{urea\_increase}$$

Equation 6B-36 $\$23.02_{main\_increase} + \$19.27_{aux\_increase} + \$3.91_{urea\_increase} = \$46.20 / person_{total\_increase}$

Equation 6B-37

$$\frac{\$46.20 / person_{total\_increase}}{7days_{cruise\_length}} = \$6.60 / person / day$$

To put this price increase in perspective of the additional cost for a typical seven-day Alaskan cruise, we also determined the % increase for the various stateroom types available on the vessel. These values were established as shown in Equation 6B-38 and Table 6B-2 lists the four main stateroom types used on a typical Alaskan cruise liner.

Equation 6B-38

$$\frac{\$46.20}{Stateroom\_price(\$599)} \times 100 = 7.7\%$$

Table 6B-2 Representative Alaskan Cruise Liner Stateroom Price Increases

STATEROOM TYPE	ORIGINAL AVERAGE PRICE PER NIGHT ($)	PERCENTAGE INCREASE
Interior	$100	6.6%
Ocean View	$200	3.3%
Balcony	$300	2.2%
Suite	$400	1.7%

As can be seen from all the above price increase estimations, the additional costs of the distillate fuel and the urea required to operate in the proposed ECA will not be a significant monetary increase to the overall operation of the vessel, regardless of vessel type.

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