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CONGESTION AT LOCKS ON INLAND WATERWAYS: AN EXPERIMENTAL TESTBED OF A POLICY OF TRADABLE PRIORITY PERMITS FOR LOCK ACCESS

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Congestion at Locks on Inland Waterways: An Experimental Testbed of a Policy of Tradable Priority Permits for Lock Access[1]

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ABSTRACT

This research is focused on the problem of congestion at locks on the inland waterways of the United States, and particularly on the Mississippi and Illinois Rivers. The current policy of first-come-first-served exacerbates the problem and adds to delays and inefficiency. An alternative policy of marketable priority access permits is proposed and studied. The dimensions of the policy relative to the needs of operators are discussed. Well established economic theory suggests that the system of marketable priority permits will increase the economic efficiency with which locks operate and that by the endowing of current operators with these permits will increase their profitability. A testbed experiment was conducted to illustrate how the principles operate. The policy objective of increased efficiency is observed thereby establishing proof of principle. More importantly, the policy works according to all of the many predictions that theory holds thereby establishing design consistency. Not only is the value of system use increased, prices converge to the competitive levels, the removal of delay for certain classes of permits transforms system use to higher valued activities and operator profitability is increased. In the testbed, the policy produces the desired outcomes and it does so for understandable reasons.

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I. INTRODUCTION

Locks on the inland waterways of the United States are experiencing outages due to mechanical failures with increasing frequency. The "run down" state of the locks, particularly on the Mississippi – where many of the locks date back to the administration of Franklin D. Roosevelt, has attracted the attention of international press.[2] The U.S. House of Representatives has approved a budget of over $2 billion to expand and upgrade the locks.[3] Some question the effect on the environment and the need for such expenditure if recent figures of reduced congestion and delay accurately reflect a decrease demand for commercial use of the river.[4] Of course, the demand for commercial use of the river is not independent of the quality of the locks. Increased congestion, particularly around unplanned outages, can increase uncertainty about the delivery time and make it difficult for river carriers to compete effectively with other forms of transport.

The research reported here is focused on the problem of congestion, and concomitant delays, that occur at the locks on inland waterways. The research focused on the construction of a testbed experiment that would implement a proposed policy, and explore its effects. In addition, congestion is a growing problem; one that has grown as increased commerce and economic progress have placed a swelling demand on infrastructures, including public roads, public parks and beaches, the internet, and private railways. The research, therefore, also serves as an example that illustrates the common economic issues and helps point the way toward the solutions.

Two broad questions are asked of the experimental testbed.[5]

(i) In an environment with the essential elements of the fundamental congestion problem, does the proposed policy militate against the ill effects and solve the problem? This type of question is known as one of "proof of principle". A representative form of this question might be: "Does the policy work?" Does the policy provide the desired result? If the policy does not do so in a simple case then,

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[2] "The Nightmare Continues," *The Economist* (October 13, 2005).

[3] "The Nightmare Continues," *The Economist* (October 13, 2005).

[4] "The Nightmare Continues," *The Economist* (October 13, 2005).

[5] This methodology was introduced by Plott (1994).

the underlying ideas that motivated it are called into question and should be reexamined.

(ii) The second question is one of "design consistency". A representative form of that question might be: "Does the policy work for understandable reasons?" That is, does the policy operate in accord with the basic economic principles upon which the design rests? It is possible that "desirable" outcomes were produced by accident or random luck and if so there would be no reason to have confidence that the performance of the policy would be robust and produce the desired result if implemented at complexity and scale. The test of design consistency is a control for such possible sources of error.

The report is organized in six sections. The first section provides this introduction. Sections II and III provide the context of the problem and an overview of policy solutions that have been discussed. Section IV contains the institutional details of a proposed policy of tradable priority permits that guarantees an advantaged placement in the queue of commercial vessels for access to a lock. Lower numbers imply a higher level of priority. For example, holders of priority one permits pass through the lock before those with permits where the priority level is a higher number, even if they joined the queue earlier. A policy testbed is developed in Section V. The role of the testbed is limited as the basic economic principles on which the policy rests are well-known. The testbed is only used to demonstrate that the principles operate together as naturally presupposed by the policy, and the testbed is sufficiently transparent so as to illustrate that to those with little or no background in economics. Thus, the testbed combines many interrelated parts, each providing its own basis for comparison, into an integrated experimental session. An examination of the data demonstrates that each of these interrelated parts operated as theory would anticipate for the policy, both separately and collectively. Section VI contains the quantitative predictions of the model when applied to the testbed and Section VII contains the results that support the applicability of the policy. Section VIII, the final section, contains a summary of conclusions.

II. BACKGROUND

Lock outages and demand spikes are sources of congestion that can lead to delays for commercial traffic on inland waterways. Even when the outages are scheduled for maintenance, the outage can lead to significant delays. For example, scheduled maintenance can lead to the discovery of additional work, unexpectedly lengthening the duration of the outage and perhaps leading to a complete shutdown.[6]

Delays create additional costs for the carriers, both direct costs and indirect costs derivative of the uncertainty they generate for delivery times. Direct costs include those associated with the additional time spent waiting in the queue. Indirect costs include business lost to other methods of transport and potentially less valuable contracts, as firms using the transport service that carriers on the inland waterways provide often demand timely delivery to maintain operations.[7] For delays that can be anticipated, firms like these may try to increase their inventories as a buffer against less reliable deliveries during the delay period.[8] Of course, this may only lead to a worsening of the situation by increasing the demands on the system. Net these costs can lead to both a shifting of business to other forms of transport or increased transportation fees.

III. Policy Options and Issues

In 2000, the US Department of Defense commissioned a review of a study made by the US Army Corps of Engineers of feasibility of the current navigation system of the inland waterways.[9] The resulting committee report, sometimes referred to as the "NRC" report, encouraged further study of two non-structural measures that might improve the congestion problem, in particular: (1) tradable permits (particularly, "transferable titles to lockage slots")

[6] Consider the case of the Greenup lock on the Ohio River, where the closure that was planned to last 18 days stretched to over 52 days because of the extensive damage found and the risk of gate failure. This closure caused an average tow delay of 37.5 hours As the locks have aged, particularly over the last decade or so, the number of scheduled and unscheduled hours of outage has increased. See Planning Center for Expertise for Inland Navigation, Huntington District (February 2005).

[7] Tirschwell (March 14, 2005) ("'Each shipper has its own manufacturing schedule, but in general the cutoff date is less material than predictability,' said John Isbell, director of corporate delivery logistics for Nike").

[8] Watson (July 15, 2004) ("[C]argo … has increased 7.1 percent this year, with delays creating 'a degree of uncertainty and higher costs for companies'" and, without sufficiently close substitutes, "'[c]ompanies may have to put more inventory in the pipeline'").

[9] Committee to Review the Upper Mississippi River-Illinois Waterway Navigation System Feasibility Study; Water Science and Technology Board; Division on Earth and Life Studies; Transportation Research Board; National Research Council, "Inland Navigation System Planning: The Upper Mississippi River—Illinois Waterway," National Academy Press, Washington DC, 2001, p. 13 (hereinafter the "NRC report").

and (2) reservation system for a sequence of locks based on arrival at an initial lock.[10] Our interest is in the former of these types of market-based measures.

The broadest use of marketable permits may be in the area of environmental policy. Anderson (EPA 2001) provides a survey of various types of economic incentive schemes used, particularly by the US Environmental Protection Agency, to further environmental goals, including tradable permit programs. Stavins (2003) also surveys a number of market-based policy instruments for environmental purposes, including tradable permits, and concluding that market-based instruments are of increasing importance. Similarly, Montero (2004) argues that, while not having fully replaced "command-and-control" policies, "permit markets are expected to play an increasing role in the solution of environmental problems in the future."[11]

However, marketable permits have also been used to solve problems of congestion in the transportation sector, including airport landing rights, or "slots" and, similar station rights for railways.[12] This study, similar to Plott and Porter (1996), looks at tradable interests in priority rights rather than to exclusive use at a specified time.[13] As in the case of other waterways, such as the Panama Canal, there is a system of priorities in place – where, e.g., military vessels can move ahead of commercial vessels; however, such priorities are not generally tradable.[14]

Any policy designed to reduce the costs of congestion is forced to confront a number of constraining factors. Perhaps the most important of these are: (1) the industry's reliance on flexibility in scheduling in order to respond effectively to a variety of external forces and (2) variability in the costs of delay across carriers and shipment contracts. In addition, policies are more useful if they provide a means to measure the costs of the delays or the value of increasing the capacity of a lock.

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[10] NRC report (2001), pp. 66-71

[11] Montero (August 2004), p. 2.

[12] In the case of airlines, see, Grether, Isaac, and Plott (May 1981); in the case of railroads, see, e.g., Cox, Offerman, Olsen, and Schram (2002).

[13] See also Wilson (1993) for a discussion of pricing the provision of electricity with different levels of acceptable interruption when demand is uncertain and service unreliable.

[14] See, CBFenton (1998). Generally, the Panama Canal's priority system uses two principal means of access to the locks: (1) a reservation system for a certain number of slots for priority access and (2) the authority of the lockmaster to let any ship "be moved through the Canal on a priority basis." See CBFenton § 104.5

Previous considerations included a variety of policies that were not market-based. Lockage fees might be charged for the use of a lock and that charge might be higher at periods of peak use, or additional fees might be added for a "slow" lockage.[15] However, systems that penalize "slow" lockages were set aside, as the length of the lockage may influenced by factors beyond the control of the operators, such as weather conditions. Similarly, systems using fixed-time appointments were less attractive. Moreover, the general appeal flexibility made command and control systems unlikely to be the most useful line of inquiry. A tradable priority permit system suggested itself as likely to best serve the objectives of reducing the costs of congestion, including costs associated with uncertainty and providing a means to measure the value of increased lock capacity.

A policy of tradable permits for priority access to locks on the inland waterways can conform to the constraining factors and offer the desired benefits. Unlike fixed appointments policies, such a policy increases flexibility in shipping schedules as each party is able to decide whether to exercise, sell or hold their priority permits, which were previously not available. It also allows shipments with costlier delays to move through at a priority, increasing the efficiency of the system, while not necessarily increasing the number of lockages per day or the number of vessels, or tug-barge combinations that moved through a lock each day. Such a policy reduces the uncertainty associated with the position one may get in the queue so as to aid in operators' abilities to improve their business arrangements and pursue more time sensitive shipments. It also increases operator profits by increasing the flexibility of the operator to respond to changing market conditions, allowing the operators to better compete with alternative means of transport by reducing the uncertainties associated with delivery conditions, and allowing the operators to expand the set of contracts they can profitably undertake. The priority permits are a ready means of responding to congestion, including extended or unscheduled outages at a lock and valuing increases in lock capacity. Finally, the system has the advantage of being similar to industry self-help. See Appendix A for excerpts from a meeting with industry discussing the closure of the McAlpine Lock.

A policy of tradable priority permits is consistent with and similar to self-adopted industry policies to meet temporary difficulties; however, institutionalization of the system will

[15] See, Stavins (2003) and Volpe, (2003).

provide for a quicker response time and broader application. Commercial users of the inland waterways are familiar with priority systems and have found them beneficial to help resolve congestion in the past.[16] However, because in the past these solutions have been ad hoc, the benefits are not maximized. Motivations for the use of priorities include limits on the sources of or storage capacity for inputs of some customers and their need for a continuous supply to remain in operation.[17] Managing the uncertainty associated with delivery and with the negative outcomes that may ensue, including the closure of some plants dependent on supplies of inputs over the waterways and the exercise "transportation risk management," become of increasing significance.[18] While not an "easy task" for the industry to take on an ad hoc basis, the benefits seem clear.[19]

IV. TRADABLE PRIORITY PERMITS: POLICY DETAIL

The recommendation is to create a system of tradable priority permits that will be issued to existing river barge operators in proportion to existing and historical operations on the river. The major features of the instrument and policy variables are as follows.

A. Rights of the holder

A permit will give to the holder the right to move ahead of all vessels waiting for access to the lock and traveling in the same direction, up to the holder of a permit in the queue being exercised with equal rights. That is, the function of the instrument is not to govern access to or use of a lock. It only serves to alter the order from one of "first come first served" where there are several potential users in queue for a lock but with different waiting costs. The permits would only alter the order of access among commercial traffic; the existing priorities governing non-commercial traffic would be unchanged.

B. The Master Instrument

The tradable priority permits are instruments with two principal components: (1) the master instrument and (2) the two-week permits. The master instrument provides the holder a

[16] See, e.g., USACE Meeting (May 27, 2004), pp. 64-5: "So probably very soon, we'll probably try to put a working group together. We may look to some outside resource also to help manage that process. So, I guess unless we - FROM THE FLOOR: We've done this a lot of times. INGRAM1: Yeah, we have done this before."

[17] USACE Meeting (May 27, 2004), p. 61

[18] USACE Meeting (May 27, 2004), p. 60.

perpetual stream of two-week permits for the life of the program. So, the holder of a master instrument for a given lock will be reissued each year the same tradable priority permits for the 26 two-week periods unless and until the master instrument is sold.

C. Marketability

The instruments will be marketable and transferable. Either the master instrument or one or more of the two-week permits it generates can be marketed and sold. Sales of the latter do not affect the ownership and control of the master instrument. One may sell priority permits that are not expected to be used or not highly valued to others, while retaining the master instrument and, therefore, the ongoing stream of priority permits in the future.

D. Permit validity and timing

Permits will be designated as "Upstream" or "Downstream." The permits will be lock specific and have a limited life. The life of the permit will be sufficiently long and the grant of permits overlapping so that the flexibility of vessel operators is maintained. For example, a permit might be valid for use within a given two-week period with other permits beginning (and ending) their useful life at the end of the first week. In fact, this "overlapping" structure of instruments will add flexibility for vessel owners to meet unforeseen changes that occur during a voyage. Still, the number of permits of a given priority available to be exercised at any time is limited, so savings in delay costs are still achieved.

The queues, "Upstream" and "Downstream," are treated separately. The current procedures by which the lock masters allocate between upstream and downstream traffic is not altered by this proposal, in part, because the congestion is understood to be typically one-way.[20] However, if a priority needed to be viewed as a queue for use of the lock regardless of direction, that can easily be addressed by, as one alternative, avoiding the distinction between upstream and downstream priority and making one unified priority not conditioned on

(...continued)

[19] USACE Meeting (May 27, 2004), p. 60.

[20] There appears to be some understanding in the industry that multiple one-way locks assist in relieving congestion at locks. USACE Meeting, at pp. 56-57 (May 27, 2004) ("I guess one of the questions that the Colonel asked is do you use traditional first come first serve or do you use multiple one-way lockages. And my response to that is based on a lot of the queuing theory things that the industry has looked at over the years and worked with the Corps, we have found that multiple one-way lockage permits us to move more cargos through the lock.")

direction. Such would, of course, risk sacrificing a distinct market for upstream and downstream priorities that adds somewhat to flexibility in planning in making more precise forecasts about river use and relative priority.

E. Priority levels

Unless otherwise determined four priority levels will exist and can be labeled as 1^{st} through 4^{th}. Holders of 1^{st} level priority that present themselves at a lock during a week for which the instrument is valid will be moved ahead of all traffic holding lower level priority. Notice, that under this right a 1^{st} place holder cannot allow a lower level holder in front while holding back another 1^{st} place holder. In general, an n^{th} level holder can move ahead of any $n+1^{th}$ level holder.

Given the current tracking of tows between locks in place, this system would add only incrementally to the existing information that is now available to tows on the river. Tows are currently able to access information regarding the number of tows ahead of them in the queue. With the priority system, they would be able to ascertain the number of tows in the queue at each level of priority. In this way, they would be better able to determine whether or not they can profitably accept or compete over delivery conditions in a prospective contract.

F. Limited useful life

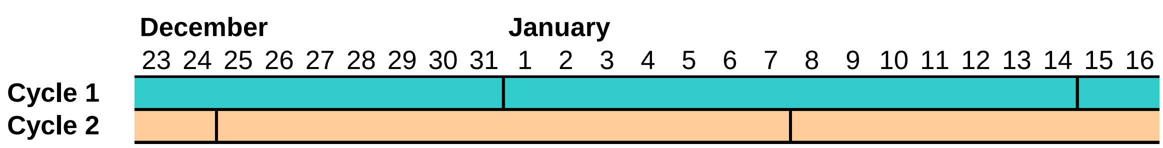
The instruments are good only for the time interval and lock for which the instrument was issued. So, in periods without congestion, the permits will expire without being exercised. Unexercised permits whose valid life is past may not ever be subsequently exercised. Of course, the following year, permits will be regenerated for that year according to the ownership of the Master Instrument.

G. The initial number and allocation of permits

The initial allocation of permits to operators and the number of permits for each priority level are related questions and, to a large extent, distributional questions beyond the scope of this inquiry. A sensible starting point for such a discussion, however, is historical use and capacities. According to Tietenberg (2003), this type of grandfathering tends to be the most common allocation method for tradable permit systems.[21] Historical capacities under various conditions can provide some insight into the number of lockages that can be accomplished under extreme operating conditions. Similarly, one can have insights into the length of time that might be required to clear a queue built up during a complete closure. Finally, patterns of use by particular firms offer some indications as to their scale and, perhaps, the type of transport service they offer.

Using this background, as a starting point for the discussion, we might begin with the number of permits at the highest priority equal to the available capacity, number of lockages that can be accomplished, during the relevant time period when congestion is at its highest levels, barring complete closure for the entire period. The relevant time interval should be wide enough to offer the flexibility that vessel operators demand. A starting point might be a window of two weeks. To increase flexibility, the priority permits would have overlapping time intervals. Master instruments and the priority permits they produce could be evenly divided across two cycles that are staggered by one week. Half the master instruments will produce permit streams that have their first two-week permit begin on January 1 and the other half will have their first begin on January 8. See figure 1 below.

Figure 1: Overlapping time intervals



The initial distribution would be relatively conservative in that the number of higher level priorities would be relatively low. This conservatism would be in order to avoid the need to downgrade priorities during the preliminary stages in which some adjustment might be required. A conservative starting distribution might, e.g., involve only 5 percent of the priorities being granted at each of the three most preferred levels of priority.

A likely solution to the distributional question would include "grandfathering" the existing operators in the sense that the existing operators receive the priority permits free of charge, or perhaps for a small administrative fee. If all else were equal, equity might suggest

[21] Tietenberg (2003), p. 410.

that each firm receive a proportional share of standard portfolios. For example, a firm with *x* percent of the lockages over the last three years will receive *x* percent of the issue of each type of permit. Those whose business models benefit from a greater than proportional share of higher priority permits would be expected to acquire them on the market from those who derive less value from them.

The number of permits and number of the level of priorities present an interesting tradeoff. With a very high number of priorities and low number of permits of each type, one might observe that, for all intents and purposes, the permits of the same priority all sell for much the same price. Firms may not be willing to pay substantially more to be first as opposed to second. However, this degree of fineness also makes it more difficult to make the initial distribution of instruments more equitable, that is, that all firms with substantial participation get at least one master instrument for each lock they use at each level of priority. If there were 10 firms that all used the same lock and only three master instruments of the highest priority, an apparently equitable initial distribution might not be possible. So, the number of permits is generally not less than the number of firms with substantial participation at the lock. Moreover, larger numbers of master instruments ease trade among the participants and make pricing more distinct as between priorities.

Ultimately, the initial distribution of permits involves complex questions of equity among the operators that lie beyond the scope of the question of the effect that such a system would have if implemented. While the factors mentioned above offer some guidance as to the considerations that would be addressed, the process of arriving at a consensus on an equitable distribution is largely a political one. However, we can add to this list of factors an adjustment rule for the total number of licenses at each level of priority. The rule, developed in detail in Appendix B, is based on a comparison of the cost of congestion to the relative prices of the permits. If the difference between the high and low priority permits exceeds the cost of congestion, then adding a permit at the highest level would be efficiency enhancing.

H. Recording System

Each master instrument and associated two-week permit is numbered; a record of the owner will be kept by the Corps and made publicly available. These numbers will relate so that each two-week permit can be associated with the master instrument that produced it and the time period for which it is valid. For example, the master instrument might be AAA111 and the two-week permit transfers of ownership are valid only after official notification to the Corps. The record of ownership held by the Corps will be the determining factor in the case of disputes, suspected fraud, forgery, or other suspected misuses.

I. Enforcement

The ownership of the master instrument and associated permits will be kept by the Corps and be available to both lock masters and any vessel that might wish to offer to purchase a priority permit from another operator.

The lock master will direct repositioning of tows in accord with the permits held by those who might approach the lock and state they are exercising a priority permit. This can be done in accordance with current practice and the existing tracking and communication systems. The lock master will verify the number of the certificate held by the operator using the lock. The nature and punishment for violations and failure to comply will be determined by the Corps. The exercise of any priority permit is conditioned on it being possible to safely alter the queue based on all the prevailing facts and circumstances.

V. POLICY TESTBED

While the policy is based on fundamental principles of economics that are fully understood by the scientific community and professional economists, these principles might be unfamiliar to those who will be affected by the recommendation. In order to illustrate the nature of the proposed institution, the problems it addresses and how it accomplishes a solution an experimental testbed was conducted. This testbed serves as both an illustration of the recommendation together with an explanation of why and how it is expected to work. The concepts and the setting are complex; so, the testbed demonstration within a highly simplified setting should help to develop an understanding of the recommendation. The simplicity of the setting is necessary to expose the operation of the underlying economics that is not compromised by additional complexity.

A. Questions for the policy testbed

The policy proposal suggests important questions that can be answered in the context of the policy testbed.

- First, can the proposed market system be practical in the sense that it can be put into operation?

- Second, are the principles on which the proposed system is based apparent in the testbed such that the proposed system works for understandable reasons?
- Third, when implemented, does the proposed market system have the expected effects?

The construction and implementation of the testbed requires operational and measurable concepts; so, the very creation of the testbed provides an affirmative answer to the first question. By observing the proposed system at work in the simple case of the testbed, we would hope to see that participants who are unfamiliar with the technical aspects of economics can nevertheless develop a common sense intuition of the proposed system's foundations as evidenced by their ability to successfully use the new market instruments to improve their performance without extensive training. Of course, the final question is answered by the results of the testbed.

Consistent with our purposes, we use a straightforward design that begins with a "first-come-first-served" environment that operates for several periods. Then the environment is changed by an implementation of priority permits. This design permits the study of the operation of the basic principles in the context of an environment in which congestion can operated to dampen efficiency and a comparison of that environment within the context of a different set of institutions that are designed to remove important aspects of congestion cost.

B. The Testbed Environment

For simplicity, and without loss of generality, assume that there are 9 operators, each of which own and operate 5 vessels, or tug-barge combinations. All of these operators have opportunities to make contracts to move barges of cargo through a lock. The current capacity of the lock, which may be interpreted as an impaired capacity, is insufficient to allow passage of all 45 vessels on the same "day." Only 9 lockages are possible on a given day, so the passage of all vessels takes 5 days to complete. As all vessels are idle and need to move through the lock to complete a contract, there is an excess demand for lockages and a queue will form and most of the vessels will experience some degree of delay.

The testbed proceeds in terms of a number of fixed time periods. Each period represents five days and sufficient time to complete all contracts.[22] The first 10 periods of the

[22] Of course, if we allowed for the recontracting of vessels that had completed their journey through the lock, we would increase the total number of voyages possible and the profits of the system. However, the increase in the (continued...)

testbed have the participants operating under a "first-come-first-served" regime. Each subject controls five vessels that arrive in random order at the lock.

Table 1

Delay, Contract Type and Contract Value

Contract Type	Day on which the boat passes through the lock: 1st	2nd	3rd	4th	5th
	(value)				
(a)	(b)	(c)	(d)	(e)	(f)
A	1,000	0	-100	-500	-750
B	500	400	0	-100	-200
C	400	300	200	0	-100
D	300	200	100	100	100

Table 1 contains the value of various contracts as depending on delivery time. As can be seen from the values in Table 1, the contracts available differ in payoff and risk dimensions. Contracts of type A have a relatively large payoff if the delivery time is short. Notice, however, that the losses from delays in completing this type of contract are also relatively large and increases with the length of the delay. Contracts of type B produce a substantially lower payoff than those of type A if delivery is relatively quick; however, the loss exposure is also not as great due to delay. For contracts of type C, the payoff for a quick delivery is reduced as are the penalties for delay. Contracts of type D are "safe" contracts, in that it has a similar expected payoff to type C with random delivery times, but does not involve any negative values regardless of the length of the delay.

Opportunities to engage in different forms of contracts differed dramatically across vessel operators. In particular, one-third of the operators had the opportunity to engage in type A contracts while others did not. The reason for this asymmetry was to illustrate how the patterns of profits would be affected across vessel owners with different shipping opportunities. Different opportunities may be the result of different business relationships or the particular capabilities of the vessels themselves.

(...continued)

value of those additional lockages would be approximately proportionate to the ones we observe and would not alter the qualitative results of these preliminary tests. Part of the payoff structure in the contracts can be interpreted as relating to opportunities for additional contracts on the other side of the lock.

Theory tells us, basically, that the benefits of the proposed policy will accrue neutrally in the sense that the benefits of the policy will tend to be equally shared among existing operators regardless of any differences they may have in their opportunity set. The testbed allows a means of supporting this prediction if all the vessel owners' profits increase, notwithstanding the fact that only one-third of them had the ability to make contracts of type A. The proposed system includes an even distribution of priority permits to all operators in proportion to historical river use but independent of the nature of that use. Thus, each operator will receive a portfolio that included instruments for all levels of priority. Operators who do not have openings to markets with high payoff contracts are able to sell these priorities to those who do and thereby share in the gains.

VI. A Model of Permit Prices

The implications of the apparent market realities and economic principles upon which the proposed policy is based, the competition equilibrium model, can best be understood by first considering a continuous model. We assume that each agent is of a fixed size (e.g., limited number of vessels (or tug-barge combinations)) and can deploy a vessel only once during the time frame under consideration.

The notation used throughout will be as follows:

m = the number of agents

n = the number of different types of permits

x_{ij} = the number of j^{th} priority permits held by agent i

$x^i = (x_{i1}, .., x_{in})$

p_j = the equilibrium price of j^{th} level permit

B_i = the number of vessels owned by agent i (i.e., the size of i's fleet)

$v^i(x^i)$ = the value that agent i placed on the portfolio of priority merits x^i.

s_j = The fixed market supply of level j priority permits.

The market supply quantities could be considered as having been distributed as intended endowments and no confusion would follow except possibly when overall profits are computed and at that time the assumptions will be made clear.

The theory of competitive equilibrium has agents solving the problem:

$$max\ v^i(x^i) - \sum_{j=i}^{n} p_j x_{ij}\ ,$$

subject to $\sum_{j=i}^{n} x_{ij} \leq B_i$.

Assume an interior solution for simplicity and purposes of explanation. We have as equilibrium conditions:

(1) $\sum_{i=i}^{m} x_{ij} = s_j ; j = 1,...,n$ (demand equals supply for all levels of priority)

(2) $P_j = P_k + \left[\frac{\partial v^i}{\partial x_{ij}} - \frac{\partial v^i}{\partial x_{ik}} \right]; i = 1,...,m; j = 1,...,n$ (the difference between the prices of two different levels of priority is the difference in profitability of the marginal unit.)

In the discrete world of the testbed, the equilibrium allocation and prices are as in Table 2.

Table 2

Equilibrium For Competition Model Given Testbed Environment

Permit Regime (a)	Permit (b)	Price (c)	Contract Type (d)	Cargo Value (e)
First Come, First Served				
	No Permits	0	D	100
Priority Permits				
	1st priority	900	A	1,000
	2nd priority	300	B	400
	3rd priority	100	C	200
	4th priority	0	D	100

The information content of equilibrium prices includes the value of increase of the lock capacity. The following example taken from Table 2 illustrates the principle. An increase in lock capacity will increase commodity flow up to the resource constraint imposed by the number of vessels. All vessels are fully utilized in the test so an increase in lock capacity will not increase the total number of shipments but it will change the composition of shipments. The following changes will take place, theoretically, if the capacity is increased to let one more vessel through the lock under first priority conditions. First, one vessel will stop shipping with a permit of priority two and instead use a permit with priority one. In so doing, it will stop making contracts of type B and begin making contracts of type A. The implied gain from this change is 600. Second, another vessel will stop shipping a C under priority three and acquire the second priority that has become free. This leads to a gain of 200. Subsequently, a third vessel will move from the shipping of a D contract to a shipping of a C contract, creating a gain of 100. The remaining vessels will continue to ship D contracts, leaving the gain unchanged. The total gain therefore is 600+200+100, or 900. The value of increasing the lock size to accommodate one additional priority one permit equals 900, i.e. the price of the priority one certificate.

Likewise, suppose the lock capacity is increased to allow one more of all classes of priority to be used. The gain is one more priority one permit, creating a shift from a D contract to an A contract, leading to a gain of 900; additionally, there is one more priority two permit, creating a shift from a D contract to a B with a gain of 300, and one more priority three permit, leading to a shift from a D contract to a C contract, creating a gain of 100. Finally, all vessels are used so there is no additional traffic of cargo D. The total gain is therefore 900+300+100, or 1300. The sum of prices is also 900+300+100, or 1300. Thus, priority prices can be used to compute the implicit value of increasing the lock size. Of course if additional vessels are free and if the increase in lock capacity means that three more D could be processed by the lock then that gain can be added to the benefit calculation.

VII. RESULTS

The first 10 periods of the testbed were under a policy of "first-come-first-served." Beginning in period 11, a system of priorities was implemented.[23] The results of this first treatment of the testbed relative to the second confirm that the delays, directly and through the associated uncertainty, have an impact on the type of contracts made by operators. We have five principal results. The first result addresses the types of contracts chosen and the second result addresses the economic value produced by contracts and how the value changes as institutions change. The third result is focused on prices. The fourth and fifth results report the impact of policies on the size and distribution of profits.

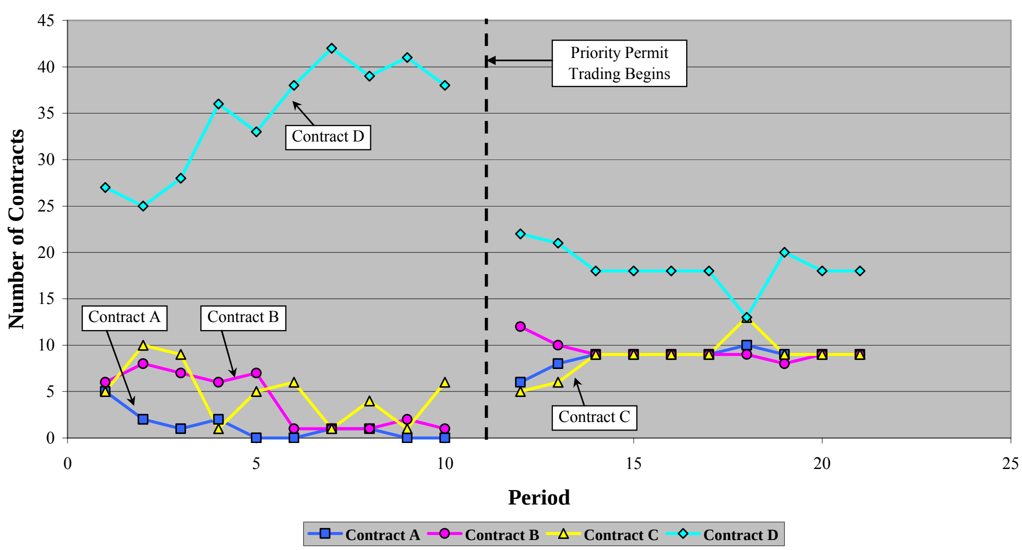
RESULT 1. *The risk of lock delay impacts the nature of the cargo and contracts transported through the river system. The "first-come-first-served" policy discourages high value contracts with fast delivery requirements. The introduction of the priority permit policy is accompanied by an immediate change in the types of contracts shipped from the low valued contracts to the high valued contracts.*

Figure 2 demonstrates the contracts chosen over time. The policy change takes effect for period 12, with period 11 as a period of transition and instruction. As can be seen in figure 2, above, the shift in the type of contracts characterizing cargo is immediate. The use of the most valuable types of contracts, those of types A and B, are increasing from zero while the use of the least valuable types of contract, those of type D, plummets. Again, such evolution of markets takes place over time reflecting the long range investment decisions.

During the first 10 periods, the contracts with the least potential economic value, those of type D, swell in use while the contracts with the most potential economic value, those of types A and B, essentially disappear from use in the market. For our purposes, this diminished use of types A and B contracts can be thought of as representing business lost to other forms of transportation, perhaps in the form of technology and location decisions to base businesses on transportation footings other than river traffic.

Under the "first-come-first-served" policy, then, these contracts of high potential value and high-risk appear to be avoided in favor of low potential value and low-risk contracts.

Figure 2: Number of Contracts Made by Type



Source: Testbed Data.

(...continued)

[23] However, in period 11 there were technical problems and the data were not used.

The number of transportation contracts executed each period was 45 for most periods. The only exceptions were the first period and the first period after the introduction of the permits. However, a change in the types of contracts shipped occurs almost immediately with the introduction of the tradable priority permits. This can be viewed statistically as the distribution of contracts shifting away from the low-risk low-reward contracts of type D in favor of the higher valued but riskier contracts of type A and B with the introduction of the tradable permits. In particular, the higher value contracts, which also have higher penalties for delay, were executed more frequently when the uncertainty was removed by the priority permit, while the contracts that have little variance in their value based on the time of delivery were executed less frequently.

The mean number of contracts for each type both before and after the introduction of tradable permits is provided in Table 3. Difference in means tests for each pair confirm that contracts of types A, B, and C were executed more frequently and contracts of type D were executed less frequently after the tradable permits were introduced, while the total number of contracts executed remains essentially constant.

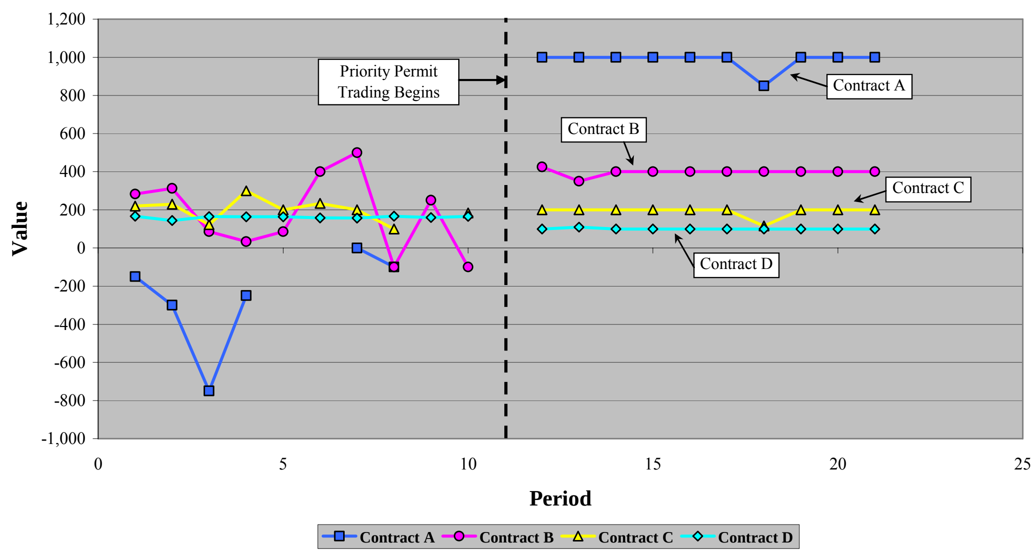
Table 3: Difference of Means Tests for the Number of Transportation Contracts Executed by Type

	Contract Types				
	A	**B**	**C**	**D**	**Total**
	(a)	**(b)**	**(c)**	**(d)**	**(e)**
Mean Before Permit Trading ($\bar{x}_A$)	1.2	4.0	4.8	34.8	44.8
Mean After Permit Trading ($\bar{x}_B$)	8.7	9.3	8.6	18.4	45.0
t-Statistic	-12.637	-5.239	-3.138	7.760	-1.000
H_o: Diff = 0					
Prob H_{a1}: $(\bar{x}_A - \bar{x}_B) < 0$	0.000	0.000	0.003	1.000	0.165
Prob H_{a2}: $(\bar{x}_A - \bar{x}_B) \neq 0$	0.000	0.000	0.006	0.000	0.331
Prob H_{a3}: $(\bar{x}_A - \bar{x}_B) > 0$	1.000	1.000	0.997	0.000	0.835

The next result, Result 2, provides intuition for the dramatic shift in the type of contract used. The key resides in the realized values of the contracts. While A and B contracts have higher potential value, they are also associated with a higher risk of loss due to delay. As might be expected, in periods of congestion the delay reduces the average return realized for the contract. The high risk contracts are not profitable because operators can not respond to the congestion by reducing the uncertainty associated with their arrival time and their expected delay. Therefore, operators respond instead by choosing contracts that have higher economic value when delays are encountered, i.e., D contracts.

The patterns of use observed in Figure 2 reflect the relative risk. Contracts of type B, which are low risk compared with those of type A, are initially made; however, experience with losses forces that type of contract from the market. Use of C contracts, which have still lower risk, is also attempted but are less favored than contracts of type D, which have a similar expected payoff and a better worst case. Within the "first-come-first-served" regime there is no mechanism through which operators can capture the value of contracts A, B and C. So, the use of these types of contracts all but disappears.

Figure 3: Average Realized Value of Contracts by Type



Source: Testbed Data.

The realized value of a contract is dependent on the time of delivery. The introduction of a system of tradable priorities has the clear effect of increasing the frequency with which higher value contract types are successful in arriving on time and thus increases both the expected and realized value of such contracts. This change in the realized value is captured by the second result.

<u>RESULT 2.</u> The average realized value of the more time-sensitive contracts increased with the introduction of tradable permits, while the average realized value of the relatively low-value and less time-sensitive contracts of type D fell.

Figure 3 illustrates the impact of the policy of tradable priority permits on the realized value of contracts. The realized value of contracts is determined by the day on which the vessel carrying the contract's cargo clears the lock in accordance with the values in Table 1. As noted above, contracts of type A are penalized heavily for delays at the lock. In the absence of priority permits, the realized value of contract A is negative and the realized value of contract B has a high variance and is declining. The realized value of contract D is positive and without variance and the realized value of contract C is similarly positive with some variance.

With the introduction of priority permits, the average realized values of the contracts take on a more stable set of relationships and, most notably the average realized value of type D contracts declines. Since the payoff structure of D contracts does not provide a sufficient incentive for the use of higher level priority permits, vessels executing type D contracts are more frequently locking through on the later days where the realized values are lower once the permits are introduced. The realized value of type A contracts begin with a negative average realized value and a frequency of use diminishing to zero; however, with the introduction of priority permits, they have the highest average realized value and steady and substantial use. The number of D type contracts, which had experienced an increase in use prior to the introduction of the tradable permits, falls off with the introduction of the tradable permits to be replaced by an increased use of contracts of types A, B and C.

The visual impression of Figure 3 and the associated discussion are supported and made more precise with the statistical tests presented in Table 4. The differences in average realized values of contracts before and after the introduction of priority permits are statistically significant in all cases.

Table 4: Difference of Means Tests for the Value of Transportation Contracts Executed by Type

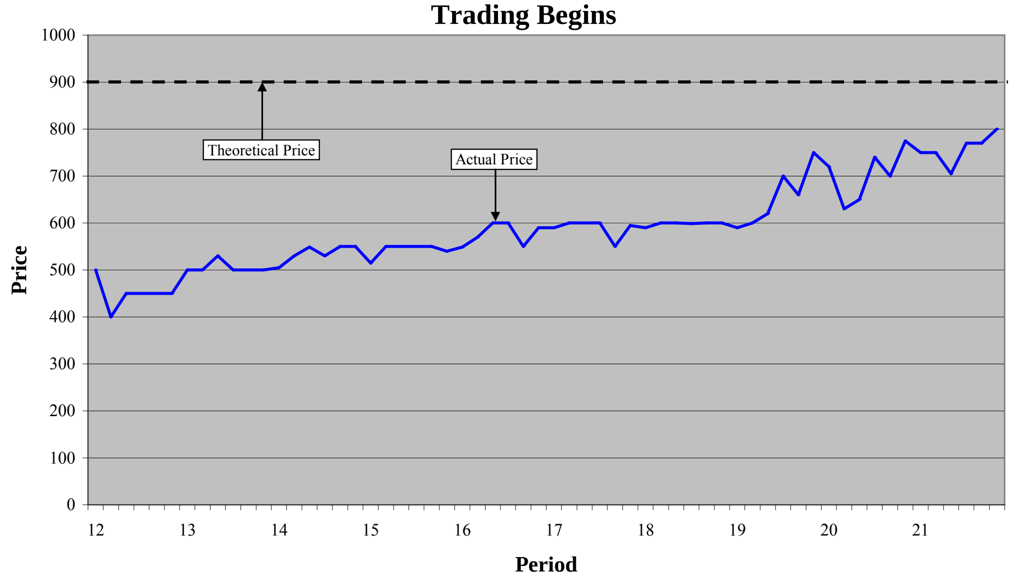
	Contract Types				
	A (a)	B (b)	C (c)	D (d)	Total (e)
Mean Before Permit Trading ($\bar{x}_A$)	-270.0	680.0	890.0	5610.0	6910.0
Mean After Permit Trading ($\bar{x}_B$)	8,550.0	3,700.0	1,620.0	1,860.0	15,730.0
t-Statistic	-27.525	-9.959	-3.089	10.890	-26.943
H_o: Diff = 0					
Prob H_{a1}: $(\bar{x}_A - \bar{x}_B) < 0$	0.000	0.000	0.003	1.000	0.000
Prob H_{a2}: $(\bar{x}_A - \bar{x}_B) \neq 0$	0.000	0.000	0.006	0.000	0.000
Prob H_{a3}: $(\bar{x}_A - \bar{x}_B) > 0$	1.000	1.000	0.997	0.000	1.000

The results of the testbed support the idea that the proposed policy produces exactly the type of results that the underlying principles indicate should result. Result 3 that follows, helps focus on exactly how it happened and why it happens. In particular, the next three figures demonstrate that the mechanism through which the policy operates can be well understood in terms of basic economic principles. The operators acquire the priority permits before soliciting the types of contracts they ship. Thus, with a permit of priority one, an operator is guaranteed a faster passage and can more safely enter into higher value types of contracts. The potential value of the contracts creates value for the permits and thus becomes reflected in the permit prices. Only those whose shipping plans can benefit from the higher priority will pay the high price for a permit of priority one.

The laws of supply and demand tell us exactly what those prices should be. Relying on these laws, we can determine the equilibrium prices for each permit type and use these as predictions to compare with the results of the testbed.

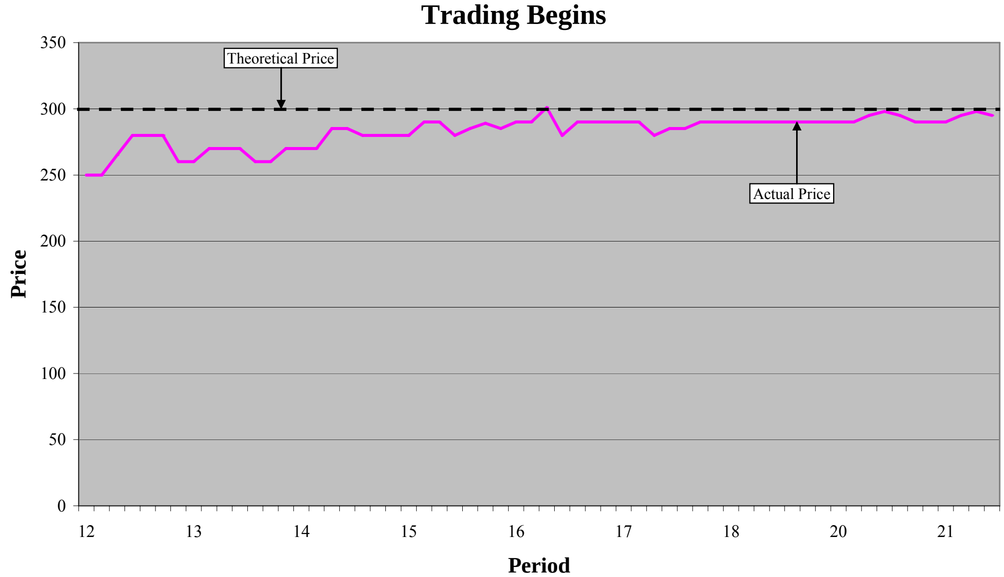
Figures 4, 5 and 6 contain the data on the price of each of the contract types over time. The prices converge over time toward the prices predicted by the laws of supply and demand. Specifically, the price of permits of priority one converges toward the predicted equilibrium price of 900. Similarly, the prices of permits of priorities two and three converge to their predicted prices. In the testbed, permits of priorities four and five traded at an insufficient volume to justify a figure; they command a price of zero, which is consistent with the basic principles.

Figure 4: Market for Priority 1 Permits After Priority Permit Trading Begins



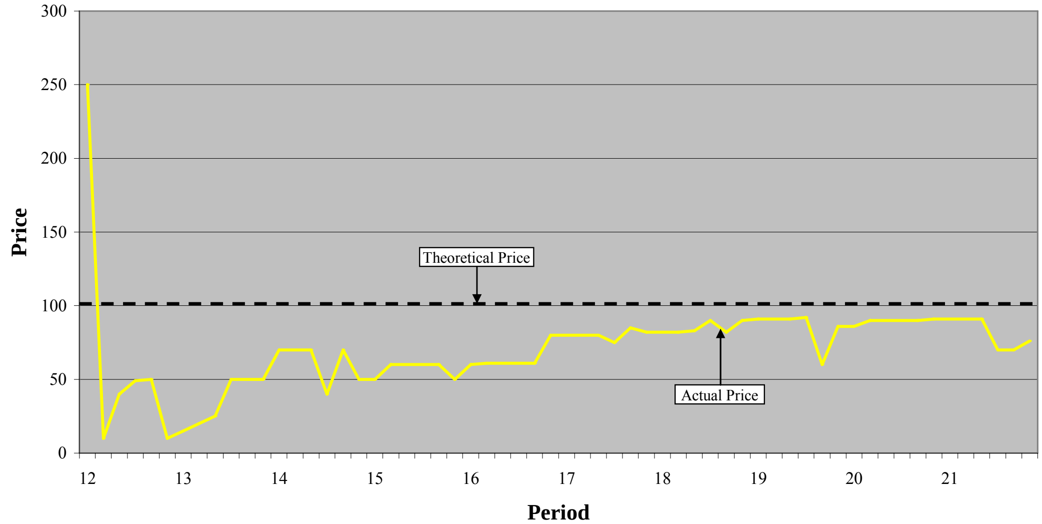
Source: Testbed Data.

Figure 5: Market for Priority 2 Permits After Priority Permit Trading Begins



Source: Testbed Data.

Figure 6: Market for Priority 3 Permits After Priority Permit Trading Begins



Source: Testbed Data.

<u>RESULT 3.</u> Permit prices evolve toward those consistent with basic principles of economics.

The figures above carry the impression that the prices are converging to the competitive equilibrium of the system. The statistics make that intuition precise. Following Noussair, Plott, and Riezman (1995) and (1997), we can use an Ashenfelter-El Gamal ("AEG") model for the price convergence for permits at each level of priority as follows:

$$z_t = B_1 \frac{1}{t} + B_2 \frac{t-1}{t} + u_t,$$

where z_t is the price of permits of a given level of priority in period t, B_1 is the point of origin for the evolving market price, B_2 is the asymptotes towards which the market price has converged, and u_t is an error term.

We ran three regressions based on this model, one for each market. Using a Newey-West procedure, the standard errors are robust to both arbitrary heteroskedasticity and arbitrary autocorrelation. The market for permits of the lowest priority level did not involve a sufficient number of transactions; however, the results for priority levels 1, 2 and 3 are presented below in Table 5. The estimated asymptotes for the prices for each level of priority are 660, 294, and 79, respectively. These estimates have the same rank and similar values to those of the theoretical predictions of 900, 300, and 100.

Table 5: Regression Results for the Permit Prices of Each Priority Level

Priority Level of Permit (a)	Number of Observations (b)	Origin (c)	Asymptote (d)	Theoretical Equilibrium Price (e)
1	10	399.923 *	663.513 *	900
		(39.464)	(45.014)	
2	10	260.639 *	292.084 *	300
		(4.493)	(2.835)	
3	10	56.514 *	75.632 *	100
		(15.040)	(10.830)	

Notes: - Standard Errors are listed in parentheses.
* Number is significant at the 0.01 level.

Another way to view the value created by the introduction of the priority permits is through system efficiency measures. The system is 100 percent efficient if system wealth is maximized. This is the standard cost-benefit measure applied to the testbed environment. As the next result, Result 4, demonstrates, the proposed policy accomplishes that goal. By measuring system efficiency under both the "first-come-first-served" system and under the system of priority permits we are able to measure the value created by the system of priority permits and see that this value creation is a direct result of economic efficiency enhancement.

Since the parameters of the environment are known, via the construction of the testbed, we can determine the "socially optimal" (in a cost-benefit sense) pattern of contracts. The social optimum is almost immediately obtained once the priority permits are instituted. Not only does contracting shift to the optimal distribution; the shipments are coordinated in an optimal queue for processing through the lock. Recalling that Type A contracts have a value of 1,000 when they clear on the first day, we see in Figure 3 that they are processed on the first day of the period, those of type B on the second day of the period, and so on. The coordination optimizes industry profits and the overall value of river use.

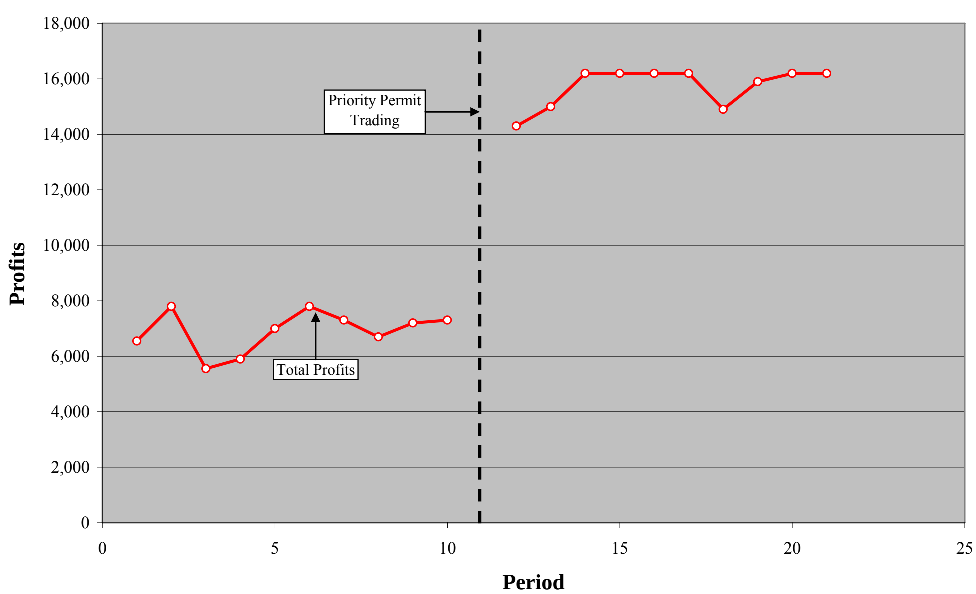
RESULT 4. The priority permit system operates to maximize total profits of operators. The system operates at 100 percent efficiency from a cost-benefit measure. Both the "first-come-

first-served" and the priority system are near the predictions of the models when applied to the two systems.

Figure 7 contains total system profits, the sum of all operators' profits for each period. The first 10 periods are profits under the "first-come-first-served" system and from period eleven on the system is operating under the priority system. Two facts are apparent from figure 7. First, the system performance is almost exactly as predicted by basic economic principles. Clearly, the models capture the essence of what is taking place in these complex interactions. Secondly, total profits increase dramatically with the introduction of the proposed policy.

This increase in wealth comes from two sources of increased system efficiency: (1) the processing of the shipments at the lock reflects the relative time value of the cargo and (2) the increased value due to the reduction of uncertainty. The former reflects the decentralized, self organizing process of markets in which the cargo with the greatest time value is shipped with the highest priority. The shippers do this as a natural part of managing their affairs. With the latter, shippers are able to engage in contracts of a different sort that have a greater dependence on time value. Thus, the cargo shipped in general under the Priority Permit system has greater value due to the removal of the uncertainty. Under the first come first serve system the uncertainty forces shippers to compromise by choosing to engage in contracts that have less time sensitivity and less overall value.

Figure 7: Total Profits to All Shippers



Source: Testbed Data.

Beginning with the same basic AEG model for profits as we used for prices, we add an interaction term to measure any change in the asymptote in periods with the tradable permits relative to those without the tradable permits, i.e.,

$$y_t = B_1 \frac{1}{t} + B_2 \frac{t-1}{t} + B_3 d \frac{t-1}{t} + u_t$$

where d is a dummy variable that is equal to one in periods with tradable permits and y_t is the total profits for each period of all the participants in the testbed. The results of this regression, again with robust standard errors, are reported in Table 6. We observe that the estimated coefficient for the interaction term is both positive and statistically significant, indicating that the introduction of the tradable permits increased the expected period profits for the group as a whole.

The final result is with respect to the distribution of the benefits and answers the question: To whom does all of the increase in wealth accumulate? The answer to this question is closely tied to the manner in which the initial distribution of permits is made among the operators.

Table 6: Regression Results for Total Profits and Profits for Each Individual

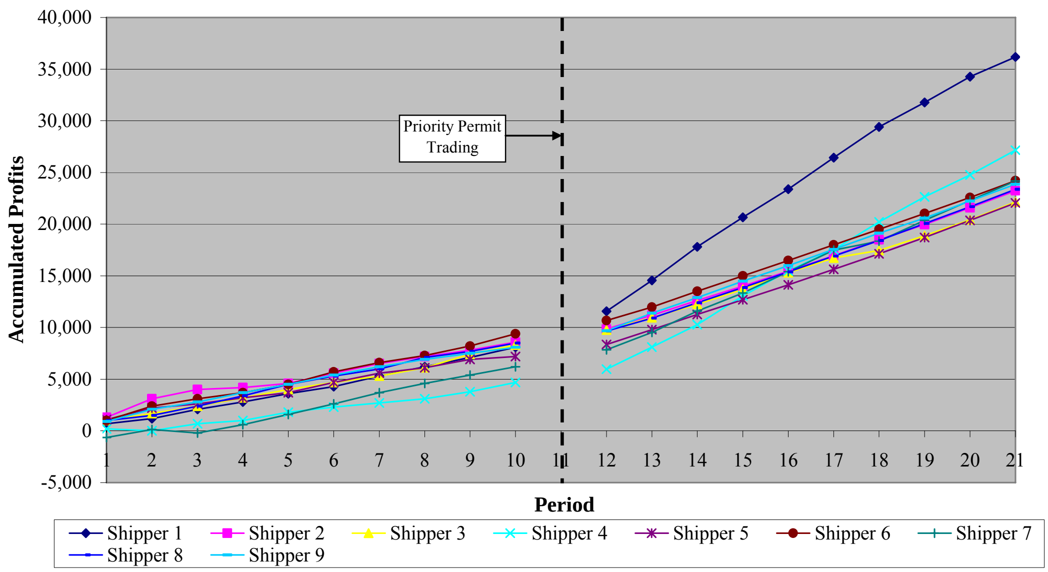
Participants (a)	Number of Observations (b)	Origin (c)	Asymptote (d)	Permit Effect (e)
Total	20	-10,238.58	56,210.65 *	110,848.60 *
		(13,435.52)	(9,595.38)	(28,868.04)
1	20	-1,687.38	6,405.59 *	20,192.37 *
		(1,959.01)	(1,233.32)	(4,884.47)
2	20	-119.94	7,453.41 *	10,118.48 *
		(1,195.55)	(909.11)	(2,693.97)
3	20	-815.36	6,503.94 *	10,497.02 *
		(1,410.36)	(1,110.70)	(2,604.58)
4	20	-1,625.09	3,417.04 *	14,503.39 *
		(1,507.42)	(833.32)	(4,109.75)
5	20	-467.40	6,237.97 *	9,943.04 *
		(1,273.80)	(931.88)	(2,735.33)
6	20	-873.45	7,623.18 *	11,036.06 *
		(1,494.41)	(1,179.80)	(2867.84)
7	20	-2,695.18	4,415.44 *	13,036.69 *
		(1,684.20)	(1,297.69)	(3,366.79)
8	20	-1,088.56	7,074.67 *	10,495.06 *
		(1,566.77)	(1,151.54)	(2,874.91)
9	20	-866.23	7,079.41 *	11,026.53 *
		(1,378.68)	(977.43)	(2,824.90)

Notes: - Standard Errors are listed in parentheses.
- Permit Effect = *Permit Dummy* * ((t-1)/t).
* Number is significant at the 0.01 level.

RESULT 5. The distribution of profit opportunities is distributed equitably among the existing shippers so that the wealth created by the introduction of the priority permit system is shared equitably among them.

Figure 8 contains the accumulated profits for each of the shippers over the time of the testbed. They all grow at about an equal rate. All increase and none decrease. Even with fairly balanced growth, we can see that one operator's profits grew somewhat faster, due to the aggressive purchase permits of priority one when their price was low relative to market value. This shipper recognized the potential and was an early catalyst in developing the most lucrative market. Since all shippers had a portfolio that included some of all priorities of permits, those who were not able to actively participate in the taking of higher valued contracts were able to profit nonetheless by the sale of their permits of priority one, two and three and then specialize in the lower priority cargo opportunities that were available to them.

Figure 8: Accumulated Profits by Individual Shippers After Priority Permit Trading Begins



Source: Testbed Data.

To test for an effect on period profits for each participant we altered the model keeping regressors for common origin and initial asymptote but adding individual interactions between a dummy variable that is equal to one for periods of tradable permits for observations relating to subject *i* and zero elsewhere and (t-1)/t. The results are presented in Table 7. The estimated coefficient for every participant is positive and statistically significant. Thus, the asymptotic level of period profits increased with the institution of the tradable permits.

$$y_{it} = B_1 \frac{1}{t} + B_2 \frac{t-1}{t} + \sum_{1}^{m} B_{i3} D_i \frac{t-1}{t} + u_{it}$$

Table 7: Regression Results for Profits of the Individual Testbed Participants Before and After the Introduction of Tradable Permits

Regressors	Number of Observations	R^2	$\bar{R}^2$	Coefficient Values
(a)	(b)	(c)	(d)	(e)
Origin	180	0.7765	0.9204	-1,137.62 ** (559.63)
Asymptote	180	0.7765	0.9204	6,245.63 * (424.35)
Permit Effect for Individual:				
1	180	0.7765	0.9204	20,313.04 * (3,893.49)
2	180	0.7765	0.9204	11,398.98 * (2,089.42)
3	180	0.7765	0.9204	10,778.36 * (1,897.13)
4	180	0.7765	0.9204	11,639.97 * (3,342.86)
5	180	0.7765	0.9204	9,983.28 * (2,121.65)
6	180	0.7765	0.9204	12,432.50 * (2,119.86)
7	180	0.7765	0.9204	11,095.19 * (2,514.08)
8	180	0.7765	0.9204	11,327.61 * (2,153.80)
9	180	0.7765	0.9204	11,879.71 * (2,185.60)

Notes: - Standard Errors are listed in parentheses.
- Permit Effect = *Permit Dummy* * ((t-1)/t).
* Number is significant at the 0.01 level.
** Number is significant at the 0.05 level.

VIII. SUMMARY

The proposed policy does not increase lock capacity, nor can it change the peak load aspect of the system in the upper Mississippi. While the proposed policy does increase the economic value associated with river commerce by reducing the cost associated with congestion, it does not decrease the amount of river traffic or increase the number of possible lockages. Some measure of congestion will likely remain in the system when demand is relatively high, but the delays associated with that congestion will be less costly. That is, the policy increases the value of the use of the river to all parties. Moreover, the market prices of the priority permits provide a measure of the value of avoiding those delays and, therefore, to reducing congestion.

The proposal is made using some terms of art from economics but no language here is intended to take account of the legal or regulatory definitions that might be part of the surrounding legislation and administration. The instructions used in the preliminary testing of the model were written so that a reader applying the ordinary meaning of the words would understand the economic setting and their role and incentives. Should this proposal be formally adopted, the implementation should include a legal review to avoid any unintended confusion. Of course, every effort has been taken by those involved to avoid any such confusion.

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APPENDIX A. MCALPINE CLOSURE

On May 27, 2004, the USACE held a meeting with the industry to discuss the temporary closure of the McAlpine Lock on the Ohio River. Temporary Closure of McAlpine Lock, U.S. Army Corps of Engineers Meeting, Louisville, KY (May 27, 2004). At that meeting a number of comments by industry participants highlighted both the benefits of having additional time to stockpile for the outage and, for some, the need for a steady and uninterrupted access.

> I'm $$ $$ with Century Aluminum. We have a continuous operation at Rangeland, West Virginia that without the feed stock, we'll shut and would not reopen, given the cost of starting that facility. About seven hundred employees, three hundred retirees at this point. That's our northern most plant. The feed stock that we use along with our metal aluminum is called Alumina, and it's in tight supply world wide, as a matter of fact it's selling at two-and-a-half times what it sold at a year ago. We can't surge and pull ahead very quickly. In our instance, the longer we can put this off, the better, understanding that you do need to get it fixed. So for us, if we were down in June, it would be catastrophic. See p. 34.
>
> Ms. $$ with Ormet Corporation. It's impossible to mobilize the supply in that time frame. $$'s supply, what he's talking about, is at least thirty days away from that lock right now, even if we were in a position to put enough on the river to basically cover a three-week time frame. First, we have to have our suppliers basically mobilize their supply in order to get the time frame to start moving the product into the river and through the position. If you close that lock, with even a two-week notice, we still have no potential to get the material up the river and through that lock before we would then have – be out of material. So the longer we have, the more notice we have -- you know, basically, ninety days notice would even be better, because it would give our suppliers a chance to get material to us. … Well, we have the same number of employees that $$ has. We have at least a thousand hourly employees between two facilities and if we put both that and a rolling mill in danger, $$'s plant produces product for the U.S. government that they basically need for planes for the materials for the war efforts. So, I mean, this puts the government at risk also for critical materials. See pp. 34-36.
>
> My name is $$ $$ with Bayer Corporation in Pittsburgh. We have a manufacturing plant in South Charleston, West Virginia. Key raw material will be dock side and we're a hundred percent dependent on that product for manufacture of polypropylene glycol. About ninety plus percent of the content of polypropylene glycol is propylene oxide. We are one hundred percent dependent on the river for this supply. We have no other mode of transportation other than barge. Propylene oxide is also tight around the world at this time and

it would take us at least until August to build up sufficient inventories of both raw materials and finished goods to get through the fourteen-day outage. Anything beyond the fourteen days, we feel would be – would have a significant impact on our company resulting in millions of dollars of loss for us, shut down of dozens of industries, including key manufacturing companies in the U.S. and the American automotive industry. That industry, we are a key supplier to that and that is an industry that does not have any wide spots in the line to absorb any hiccups in the supply chain. See pp. 36-37.

I'm $$ $$ with Lyondell Chemical and we supply Bayer with their propylene oxide. We're also the owner and operator of the barges that carry that material from our facilities back to U.S. Gulf. We do have a limited amount of these barges. They are specialized. We have fourteen barges in service. So it is going to be important not only before the closure on the loaded barges coming up from the U.S. gulf, but also getting barges back south, back to our plants to reload the empties. So we are in a situation where we have a limited amount of equipment to move this material up from West Virginia. So -- I think $$ mentioned -- started maybe one of the questions that we have, will there be any prioritization for equipment that is dedicated and needed to keep lines open? See p. 37.

APPENDIX B. ADJUSTMENT RULE FOR PERMITS

Optimum

In this appendix, we develop an adjustment rule for adding an additional priority permit to the system based on a comparison of relative permit prices and a given measure of the congestion cost. To begin, we characterize the optimum allocation of permits across priority levels such that the social value of the priorities at a lock subject to the constraint of the limited capacity of that lock is maximized. Priority levels can be designated as 1^{st}, 2^{nd}, 3^{rd}, etc. and these levels provide access to relative positions in a queue. That is, as the queue at a lock is formed, a vessel with priority i may queue up ahead of any vessel with priority j for all $i<j$, therefore, vessels with priority i may join the queue ahead of all vessels with priority j or higher in the queue.

More formally, let $I = \{1, 2,...,n\}$ be the levels of priority and let X_i be the number permits at priority level i available for use for an arbitrary and fixed period of time. This is equivalent to the number of master instruments. Let x_i be the number of priority i permits "in use."

Let the private value of vessels with priority i be expressed as:

(1) $V^i(x_i, \sum_{j<i} x_j)$.

The value of vessels with a given priority, i, decreases with increases in the number of vessels with a higher priority. This is so because the vessels of priority i are forced back in the queue with the arrival of all vessels with a higher priority at the lock. This relationship is the cost of delay caused by congestion and is included in the valuation function.

Let the constraint of the capacity of the lock be expressed as:

(2) $\sum_{i\in I} X_i = C$

where C is the capacity of the lock which equals the total number of vessels that can be moved through the lock during the time period under consideration.

The total social value of a pattern of lock use is given by the expression

(3) $V^1(x_1) + V^2(x_2, x_1) + V^3(x_3, x_1+x_2) +...+ V^n(x_n, \sum_{h<n}x_h)$ for $x_i \leq X_i$.

The necessary conditions for optimum social welfare are found by maximizing (3) subject to the constraint imposed by (2). If we assume that all priority levels are used to the maximum, then the conditions for the optimum number of permits in each priority level can be determined by finding the first order conditions for the optimum of (3) subject to (2). These are:

$$(4) \qquad \partial V^1/\partial X_1 + \partial V^2/\partial X_1 + \partial V^3/\partial X_1 + \ldots + \partial V^n/\partial X_1 + \lambda = 0$$
$$\partial V^2/\partial X_2 + \partial V^3/\partial X_2 + \ldots + \partial V^n/\partial X_2 + \lambda = 0$$
$$\partial V^3/\partial X_3 + \ldots + \partial V^n/\partial X_3 + \lambda = 0$$
$$\ldots$$
$$\partial V^n/\partial X_n + \lambda = 0$$

The variable λ is associated with the constraint (2) so it must be added to the set of equations (4) that describe the necessary conditions for the (interior) solution.

This optimum has a clear interpretation. Consider the equations as

$$(5) \qquad \partial V^i/\partial X_i = -\sum_{k>i} \partial V^k/\partial X_i + \partial V^n/\partial X_n$$

which says that the marginal private value of increasing the number of permits of priority *i* should be equal to the sum of the marginal cost imposed on all lower levels of priority traffic (all of which are negative) plus the opportunity cost of one less permit of the lowest priority traffic. The latter term reflects the fact that if one more vessel with a higher priority is created the overall constraint of the lock requires that the number of vessels at the lowest level of priority moving through the lock must be decreased by one. Its marginal value (positive) is the opportunity cost of the unit. Of course, all marginal values are measured at the constrained optimum from which the change is considered.

An analysis of the difference between two "adjacent" priority levels will be useful. Consider priority level *i* and the immediately lower level of priority level i+1. Subtracting the marginal social value of level i+1 from the higher priority level *i* we get:

$$(6) \qquad \partial V^i/\partial X_i - \partial V^{i+1}/\partial X_{i+1} = -[\sum_{k>i} \partial V^k/\partial X_i - \partial V^n/\partial X_n] + [\sum_{k>i+1} \partial V^k/\partial X_i - \partial V^n/\partial X_n]$$

which is simply the value of the externality of an additional permit of priority level *i* on the adjacent priority level, i+1:

$$(7) \qquad \partial V^i/\partial X_i - \partial V^{i+1}/\partial X_{i+1} = -\partial V^{i+1}/\partial X_i.$$

That is, the difference between the marginal private value of permit level *i* and the marginal private value of the lower priority level permit *i*+1 is the value of the externality imposed by the former on the latter.

Suppose the X_i have been set at some level other than the solution to (4) and (2). In that case, under suitable (convexity) conditions (7) can be used as a tool to adjust the levels and create new levels (levels that have been heretofore constrained to have zero permits).

Equilibrium

The analysis proceeds as if there is a system of marginal externality charges that will be reflected in permit prices. This tool will allow us to examine how permit prices interact in relation to the optimum.

For the purposes of this analysis, we will assume that each agent operates with a variable number of vessels and the marginal cost of a vessel is reflected in the private value functions. This assumption allows us to explore essential properties of the competitive equilibrium. In particular, when deploying vessels the agents will adjust until the marginal profit opportunities of the use of a priority permit is equal to the price of the permit. That is, for any agent *r*, the marginal profit from operating any priority level *i* satisfies the equation:

(8) $\partial V^{ri}(x_{ri})/\partial x_{ri} = P_i$.

The generality of this property allows the analysis to proceed without notation specific to the individual agent. That is, for all *i* we have:

(9) $\partial V^i/\partial X_i = P_i$.

The relationship between equilibrium expressed by (7) and the optimal number of permits as expressed by (5) can be seen through the application of a connecting model of optimal externality taxes.

Policy

Combining (7) and (9), and recalling that the externality of an addition permit of priority level *i* is negative, we have:

(10) $\partial V^i/\partial X_i - \partial V^{i+1}/\partial X_{i+1} = P_i - P_{i+1} = -\partial V^{i+1}/\partial X_i$

This tells us that the difference in price between two adjacent priority levels *should* be equal to the marginal cost of the externality that the higher level imposes on the lower, as such is a property of the optimum.

Within the context of this model, the policy implications are straightforward. If the marginal cost of the crowding of a priority level on the immediate lower level is less than the difference between the prices – then, the number of permits of the lower level priority can be reduced and the number of higher level priority permits increased by the same amount. Similarly, if the difference in prices is less than the external congestion cost then the number of the higher level priority permits should be reduced and the lower level increased.

The generalization to non-adjacent priority levels is straight forward. From (4) we can extract the equation for two arbitrary levels of priority to get:

(11) $\partial V^i/\partial X_i + \partial V^{i+1}/\partial X_i + \ldots \partial V^{i+k}/\partial X_i + \partial V^{i+k+1}/\partial X_i \ldots + \partial V^n/\partial X_1 + \lambda = 0$
$\partial V^{i+k}/\partial X_{i+k} + \partial V^{i+k+1}/\partial X_{i+k} + \partial V^{i+k+2}/\partial X_{i+k} + \ldots + \partial V^n/\partial X_{i+k} + \lambda = 0.$

Asking about the difference in marginal private values we get:

(12) $\partial V^i/\partial X_i - \partial V^{i+k}/\partial X_{i+k} = -[\partial V^{i+1}/\partial X_i + \ldots + \partial V^{i+k}/\partial X_i + \partial V^{i+k+1}/\partial X_i \ldots + \partial V^n/\partial X_1 + \lambda] +$
$[\partial V^{i+k+1}/\partial X_{i+k} + \partial V^{i+k+2}/\partial X_{i+k} + \ldots + \partial V^n/\partial X_{i+k} + \lambda]$

Let us assume the marginal congestion cost on a lower level of priority is the same for all higher levels of priority – and this assumption appears natural since all vessels with higher levels of priority must be cleared from the queue before those with a lower level have access to the lock. Those on a lower level must wait the same amount of time regardless of the order in which the higher levels of priority are served. The assumption is

(13) $\partial V^k/\partial X_i = \partial V^k/\partial X_r = q_k$ for all $i, r < k$.

Substituting and collecting the terms of (12) we have:

(14) $\partial V^i/\partial X_i - \partial V^{i+k}/\partial X_{i+k} = - \sum_{i+1}^{i+k} q_r$.

Using (9) again we have:

(15) $P_i - P_{i+k} = - \sum_{i+1}^{i+k} q_r$.

In sum, this model suggests an additional permit of priority level *i* be added if the difference in the price of a permit of that level and the price of a permit at the lowest level of priority is greater than the sum of the congestion cost imposed by an additional permit of priority level *i* on permit holders of all levels of priority less than *i*.