The Navigation Economic Technologies Program

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VESSEL, FIRM AND LOCK EFFICIENCY MEASURES IN LOCK PERFORMANCE

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IWR Report 05-NETS-R-13

Navigation Economic Technologies

The purpose of the Navigation Economic Technologies (NETS) research program is to develop a standardized and defensible suite of economic tools for navigation improvement evaluation. NETS addresses specific navigation economic evaluation and modeling issues that have been raised inside and outside the Corps and is responsive to our commitment to develop and use peer-reviewed tools, techniques and procedures as expressed in the Civil Works strategic plan. The new tools and techniques developed by the NETS research program are to be based on 1) reviews of economic theory, 2) current practices across the Corps (and elsewhere), 3) data needs and availability, and 4) peer recommendations.

The NETS research program has two focus points: expansion of the body of knowledge about the economics underlying uses of the waterways; and creation of a toolbox of practical planning models, methods and techniques that can be applied to a variety of situations.

Expanding the Body of Knowledge

NETS will strive to expand the available body of knowledge about core concepts underlying navigation economic models through the development of scientific papers and reports. For example, NETS will explore how the economic benefits of building new navigation projects are affected by market conditions and/or changes in shipper behaviors, particularly decisions to switch to non-water modes of transportation. The results of such studies will help Corps planners determine whether their economic models are based on realistic premises.

Creating a Planning Toolbox

The NETS research program will develop a series of practical tools and techniques that can be used by Corps navigation planners. The centerpiece of these efforts will be a suite of simulation models. The suite will include models for forecasting international and domestic traffic flows and how they may change with project improvements. It will also include a regional traffic routing model that identifies the annual quantities from each origin and the routes used to satisfy the forecasted demand at each destination. Finally, the suite will include a microscopic event model that generates and routes individual shipments through a system from commodity origin to destination to evaluate non-structural and reliability based measures.

This suite of economic models will enable Corps planners across the country to develop consistent, accurate, useful and comparable analyses regarding the likely impact of changes to navigation infrastructure or systems.

NETS research has been accomplished by a team of academicians, contractors and Corps employees in consultation with other Federal agencies, including the US DOT and USDA; and the Corps Planning Centers of Expertise for Inland and Deep Draft Navigation.

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Abstract: The inland waterway system is comprised of a set of rivers and associated locks and dams. Dams establish "pools" of water that allow rivers to be navigated, and locks allow barges to pass from pools of different elevations. Lock performance i.e., the timely passage of barges through the waterway depends on a myriad of factors. This study examines lock performance in terms of the structural design of locks, the characteristics of the flotilla (vessels and barges), a set of state conditions (weather, river levels, etc.), and characteristics of vessels, lock and firms. Vessel, firm and lock efficiency measures are developed using panel data techniques, and observed factors that influence efficiency are evaluated. The results point to considerable heterogeneity across vessels, firms, and locks that result in significant differences in timely passage through the locks.

INTRODUCTION

For the last 15 years, there have been on-going studies of the benefits and costs of improving the lock and dam structure of the Upper Mississippi-Illinois waterway system (UMISS) to enhance the efficiency of the system. Dams allow commercial use of waterways by establishing a set of "pools" providing depth and slower currents, while locks provide a mechanism through which waterway traffic can transition from one pool to another with different elevations.

Most of the locks in the UMISS system are were designed and built more than 50 years ago. Most of the locks are 600 feet long and 110 feet wide. But, since locks were designed and built, "flotillas" (a term used to describe a "tow" vessel and a set of barges that pass through a single lock) have grown longer. Today, the most frequent sized flotilla on the Mississippi is a power vessel pushing 15 "hopper" barges. Such flotillas are nearly 1200 feet in length. The result is that passage through the lock takes two "cuts" for the most common tow. Two cuts require more production steps than a single or than two single cuts. As such, passages take more than twice as long as a single cut. Traffic levels have grown along with the size of flotilla. Accompanying these increases has been an increase in the time to transit locks and growing queues and delays at the locks. The congestion, in conjunction with the age of the locks, has resulted in interest to redesign and invest in locks and dams on the UMISS. The primary interest is to extend key locks from 600 to 1200 feet. As an alternative to lock extensions, there has also been considerable interest in using non-structural measures (e.g., congestion pricing, lockage fees, scheduling, tradable permits, etc.). Some of these have been assessed in the Volpe report *(1)* which also provides an excellent description of the locks, policy measures, and locking processes.

An understanding of the determinants of timely passage of tows through the locks is important to evaluating the alternative policy actions. For example, recent research has examined the import of scheduling *(2)* wherein the position in the queue is predicated on the process time (fastest to transit go first). In addition, the results are useful to assess how lock extensions can affect processing times, vessel and lock characteristics affect processing times, etc. The purpose of this study is to provide to develop and estimate a model of the time it takes for flotillas to transit specific locks on the UMISS waterway. The analysis is framed in terms of standard production theory wherein passage times are explained in terms of the structural design, flotilla characteristics, state conditions, and firm characteristics. The results allow specific measures of efficiency for different locks, vessels, and firms and introduce new factors that have a statistically important effect on efficiency made possible through the use of panel data econometric techniques.

BACKGROUND

The UMISS waterway runs from Minneapolis to Cairo where the Ohio River joins the Mississippi. Excellent descriptions of the waterway are provided in *(1)* and *(3)*. The waterway has 29 locks that run from Saint Louis to Minneapolis. Of these 29 locks 25 use one chamber, while locks 14, 15, 26 and 27 have two chambers. The two chamber locks have a main lock and an auxiliary chamber. The latter is used primarily when there is severe congestion or when the main chamber is not operating.

Most locks were built in the 1930s (although, there has been considerable rehabilitation), and all but two were built more than 40 years ago. Three of the main chambers have dimensions of 1200 feet long and 110 feet wide; which is the minimum size to accommodate the standard fifteen-barge tow on the river. Twenty-two locks have main chambers with dimensions of 600 by 110 feet. The remaining four locks have dimensions less than 600 by 110 feet. These four chambers are located in the very north part of the waterway.

Since many of the locks are 600 feet long or shorter and since tow sizes have increased over time, double lockages have become more common. Indeed, using ACE data for 2000, 70 percent of lockages at 600 foot locks were double lockages. There are a number of different types of lockages. Excellent decriptions of these types are are provided by (*1), (3),* and *(4)*. An oversimplified characterization is that double lockages require more than twice the number of production steps as two single lockages. Since there are added production steps, the time to pass is expected to be and is longer, as reported later.

A number of other factors that influence lockage times. These include: 1. the configuration of the tow; 2. the type of lockage; 3. river and weather conditions; 4. the direction of travel; and 5. firm/vessel characteristics. Tow configuration may cause there to be extra production steps. The configuration requiring the fewest steps is a "straight single". In this case, the length and width of the tow does not exceed those of the lock chamber. The tow can pass through the lock without being reconfigured. Other types of tow configurations require additional production steps. In a "knockout" tow configuration, the length of the barges and towboat is too long for the lock chamber, but with reconfiguration of the flotilla, there is enough room.

There are also different types of lockages. A fly lockage occurs when the lock is idle and prepared for entry. An exchange entry occurs when an exiting flotilla and an entering flotilla, travel in different directions. In such cases, the water is at the proper level to receive the incoming flotilla. A turnback lockage occurs when the exiting flotilla and the incoming flotilla are traveling in the same direction. In such cases, the water must be "turned back" or raised (lowered) to the proper level for the inbound flotilla. If the start of lockage for these different types were from the same point, it would logically be expected that a fly lockage would be the fastest. However, fly and exchange lockages are usually recorded from points further from the lock than exchange lockages. That is, in a turnback lockage, flotillas move into a position closer to the gate as the preceding vessel is passing through the lock or as the water is being turned back. For this reason, transit times should be fastest for this type of lockage.

A variety of location factors also influence transit times. These include: the approach walls, the current of the river, weather conditions and direction of travel. Lock and dam structures cause outdrafts (movements away from the lock) and impede entry and exit. Outdrafts are easier to handle traveling upstream than downstream with the result that locking times tend to be faster upstream than downstream. The time of day (day or night) as well as weather conditions can have an influence. Water levels also influence transit times. When water is low relative to the sill of the lock, transit times are slower due to "towboat squat" wherein boats are drawn down as they accelerate. As the "clearance under the sill" falls, vessels must travel slower. Some of these effects are observable and in the empirical model. However, some lock effects are not observable and are considered in a fixed effect model reported later.

Finally, there is a wide range of towboats each of which has a set of characteristics that may affect lock transit times. Such characteristics include horsepower, screw and rudder configuration, and the length, draft, beam and hull shape of the towboat. Towboats also have a crew that have different skill levels, are attached to firms with different training programs and which have different types of equipment.

EMPIRICAL MODEL

The basic empirical model(s) rests on the production analog. Specifically, locks produce lockages. Observed in the data, described in the next section, are the times associated with individual lockages. This time is explained by a set of variables representing the number of cuts, flotilla, and lock characteristics, vessel characteristics, and a set of state characteristics. A number of different estimations are performed using panel data techniques. These give a set of efficiency measures which are then explained by auxiliary regressions. Due to the complexity of the estimation and the interpretation, the models and procedures are explained in separate subsections in the results section.

$$t = t(cuts,\ flotilla\ characteristics, lock, lockage\ type, vessel, state) + \varepsilon$$

where:
cuts is the number of cuts for a flotilla to transit a lock;
flotilla represents a set of flotilla characteristics (e.g., horsepower, number of barges);
lock represents lock characteristics (e.g., dimensions);
lockage represents the type of lockage (e.g., fly); and
state represents state variables.

The specific variables employed are in Table 1. These are discussed in detail in the next section following a description of the data.

DATA

The Army Corps of Engineers collects detailed information on the operations of locks in its Lock Performance Monitoring System (LPMS) data and are fully described and summarized in *(6)*. This information includes the dates and time of lock activities, flotilla characteristics (including the number of barges, barge types, vessels, etc), lock characteristics, and vessel characteristics. The data used in this study represent flotillas that passed through at least one of the 29 locks on the Upper Mississippi river between January 1st and December 31st of 2000. The data provide multiple observations on the same lock by different flotillas and provide multiple observations on the same vessel going through different locks with and without the same flotilla configuration. This is an excellent opportunity to use panel data techniques to uncover relationships across locks, vessels, and firms as described below.

The locks are used for commercial, government, and recreational purposes. While the analysis requires the use of all data, the econometric the econometric work is based solely on data representing commercial (non-governmental and non-recreational uses) at the flotilla level. To this end, there were 70,607 flotillas that were locked during the year on the UMISS in the LPMS data. Of these about 85% are used in the estimation due to missing data or data from other sources that could not be matched to the LPMS data.

Clearance under the sill was calculated on the basis of daily river levels and gage readings *(6), (7),* and *(8)* along with information from the NDC's lock characterisitics file and communication with districts. These data were matched on a daily basis to the LPMS data. Vessel information was taken from the NDC "On-line vessel information" file and matched to the flotilla data. After combining the data, there were records where vessel information or gage readings did not exist. Finally, there were a number of data screens to remove inconsistent (e.g., an 1100 flotilla moving in a single cut through a 600 foot lock).

All variables employed are defined and summarized in Table 1. There are a number of key variables. The variable of interest is processing time – the time to pass through a lock. It is defined as the time difference between the end of lockage and the start of lockage (in minutes). On average, time of processing is about 42 minutes for one cut and 110 minutes for two cuts (Table 1); a difference of 68 minutes. There is considerable variation across locks but that depends on the configuration of the locks and traffic passing through the locks. In particular, lock number 27 averages 43 minutes while lock number 25 averages about 102 minutes. The primary explanation is that lock no 27 has a 1200 foot chamber, while lock no 25 has only a 600 foot chamber. Thus, about 84 percent of flotillas locked at lock no 25 are double cuts, while all of the flotillas locked at lock no 27 are single cuts.

Primary flotilla characteristics include the number of barges towed, the percentage that are empty, and the length of the flotilla. As reported in Table 1, the number of barges averages about 11. The number of barges for a single cut averages about 7 and for a double cut about 14 barges. The average flotilla length, of course, is shorter for a single cut than a double. For a single cut, the average length is about 726 and for a double cut about 1064 feet. The length of the flotilla, of course, depends on the number of barges and the types of barges. While for grain and hopper movements, the sizes and types of barges are not dramatically different, but for tanker movements, there can be considerable variability. The data are dominated, however, by hopper barges (85%) and tanker barges (12%). Horsepower is an important characteristic. Too much horsepower can hinder maneuverability, while too little horsepower may not be powerful enough. The specific measure used was the tons per unit horsepower (HRPT).

As discussed earlier, there are a variety of lock dimensions. Entry of lock characteristics into the empirical model can take a variety of forms. The length, width, and/or area can be directly entered. Alternatively, since most of the locks have a 600 by 110 configuration, and only a few lock/chambers have less than 110 feet, another approach is to "dummy" the length and width of the locks. This is the approach taken here. In particular, dummies for lengths of 400, 500, and 1200 feet are entered with 600 feet is the base (D400, D500, D1200). There are two different lock widths in the data, 56 and 110. The St. Anthony and Lock 1 each have widths of 56. A dummy was entered for these lock (D56). Finally, as discussed in the next section, locks have a set of observed characteristics (discussed above) and unobserved characteristics. Examples of the latter, different locks have different outdraft conditions, approach conditions, lockmasters, etc. Each of these do not have readily available measures and/or cannot be measured. In a second specification below, the lock characteristics are treated as fixed effects, and an auxiliary regression is used to isolate observed effects.

There is a set of variables that reflect entry patterns into the lock. These include fly, turnback and exchange entry patterns. To construct these variables, the data were organized by lock number (all traffic data were used so that both flotillas for commercial use and others were in the measure) and sorted by start of lockage times. With this information, whether a lock was occupied at time of arrival or not is easily identified. If unoccupied, this was taken as a "FLY" entry. If occupied, the direction of flotilla and the last occupant was used to identify turnback and exchange lockages. A turnback entry means that the chamber was occupied on arrival and the direction of the occupant was the same as the flotilla. In such cases, the chamber must be refilled before the next lockage can begin, but the next entrant can position itself before start of lockage. An exchange entry means that the chamber was occupied on arrival, but the direction of the occupant was different than that of the flotilla. This means that the next flotilla must wait until the occupant passes before it can position itself for the start of locking. In the data, 41 percent of the lockages were fly entries; there were 30 percent exchange and 29 percent turnback entries.

Flotilla lengths and depths were included to control for the size of the flotilla. In addition, for flotilla lengths that are greater than the size of the lock, there may be a variety of different actions that a vessel operator can take to make a single cut. Specifically, operators may be able to reposition the vessel in the configuration that allows a single cut. These are commonly known as setovers, knockout, jackknife lockages. Each of these require an extra, but similar, step in the locking process. To reflect the extra step, a dummy variable "KNOCK" is employed. The bulk of these other lockage types (i.e., other than straight or consecutive) are knockout lockages. In total, the other types represent less than 10 percent of all lockages. Average lock times for single cuts are longer, on average, for these other types of lockages.

Table 1 Variable Descriptions and Statistics

Variable	Description	Overall	Single Cut	Double Cut
Time	Time to Lock	78.90	42.47	110.00
Cuts	Number of Cuts	1.54	1.00	2.00
Barges	Number of Barges	10.71	7.33	13.59
flot_length	Length of Flotilla	922.53	756.45	1064.34
flot_width	Width of Flotilla	93.36	80.01	104.76
flot_depth	Depth of Flotilla (deepest point)	7.41	6.80	7.93
Peremp	Percentage Barges Empty	34.58	38.74	31.03
b_hopper	Percentage of Hopper Barges	84.70	71.10	96.31
b_tank	Percentage of Tanker Barges	12.15	22.63	3.20
b_other	Percentage of Other Barges	3.15	6.27	0.49
Hrp	Horsepower of Power Vessel	4310	3461	5035
Knock	Dummy for Knockout, Setover, Jacknife	9.75	19.91	1.09
Fly	Dummy for Fly Lockage	41.34	46.79	36.69
Turn	Dummy for Turnback Lockage	28.59	28.42	28.74
Exch	Dummy for Exchange Lockage	30.03	24.76	34.53
Upriver	Dummy for Upriver Lockages	49.41	50.05	48.86
daytime	Dummy for Daytime Lockages	55.36	54.70	55.93
clearance	Clearance over the Sill (Ft)	10.48	12.95	8.38
Obs.	Number of Observations	59,683	27,489	32194.00

Finally, a set of "state" variables were included to capture different operating environments at the time of lockage. These include: a dummy for daytime or not, a set of monthly dummies (to reflect different weather and river conditions, etc.), and whether the flotilla is traveling upstream or downstream. In addition, as discussed earlier, an important factor is the river level at the time of passage, the depth of the lock, and the depth of the flotilla. A variable, CLEARANCE, reflects these factors. Specifically, CLEARANCE was defined by calculating the water level (from daily gage readings at each lock), subtracting the elevation of the lower sill, and the depth of the specific flotilla passing through the lock. As CLEARANCE falls, operators may need to slow to avoid bottoming out and avoiding a phenomena "Tow Boat Squat". As such, low water levels, should slow down processing time. Reinforcing this effect is the notion that as water levels rise, there is less "effective" lift between pools, and times should increase. Thus, as clearance increases, times should fall.

RESULTS

The basic goal of this paper is to develop a model of processing times. The primary factor explaining processing times is the number of cuts. Indeed, a regression of the log of lockage times on the number of cuts yields an R-square of 71 percent. To this, lock length dummies were added, and the result yields an R-square of 75 percent which is an increase of only 4 percentage points. It is also noted that the inclusion of dummies for each lock yields an R-square of 77 percent; an increase of only 6 percentage points. The full "base" model yields an R-square of 86 percent. The point of this exercise is simply to point out that a model reflecting only the number of cuts explains most of the variation. Further, the more general models (described in greater detail below) do not appear to have a large influence on the coefficient. The signs in the base model are as expected, and, generally, statistically significant.

In the base model regression results are in column 1 of Table 2. Given all else is the same, a double cut increases lockage times by about 111 percent (111%=(exp(.7476)-1)*100). Lock length generally matter. Relative to the 600 foot base, 1200 foot locks take longer but only marginally so (about 1.3%). This bears some explanation.

Given all else is the same, say a single cut of 7 barges through a 1200 foot lock takes about 1.3 percent longer than going through a 600 foot lock. Of course, this comparison is only valid given it is possible. That is, if the comparison is a 15 barge flotilla, it would require two cuts at the 600 foot lock and only one at a 1200 foot lock.

Flotilla characteristics consist of the number of barges, the tons per unit horsepower, a zero tons dummy, flotilla length, knock-out, jackknife, setover lockages, and the percentage of tankers and other barges (hopper is the base). Each has their expected signs. In particular, times increase as the number of barges increase, the tons per unit horsepower increases, as flotilla length increases, and as the percentage of tanker barges increase. Further, for largely single cut lockages wherein the configuration of the flotilla changes (i.e., knock=1), times increase to reflect the extra production step. The final flotilla characteristic is the percentage of empty barges. As expected, if the percentage of empty barges increase, the flotilla consists of empty barges, it will pass through the lock faster.

Lockage types also influence times. The base dummy is fly. Thus, if a lockage is a turnback lockage, the measured times are faster. Recall, process time is marked from the start of lockage. The typical start of lockage for a fly lockage is at the time of arrival at the approach point. At that point, the flotilla is marked for entry, and the flotilla moves into position to begin locking. For a turnback, the flotilla arrives and is in a queue. When the flotilla ahead crosses the bow, it is common place for the flotilla in queue to approach the lock decreasing the approach time once it is signaled to enter the lock (the start of lockage). In these results, the effect is about .84 meaning that a turnback lockage time is about 16 percent faster than a fly lockage. Of course, this does not mean it is more "efficient" per se in that the start of lockage likely represents a different position on the river. In contrast, exchange lockages are not statistically different from fly entries. This is because the flotilla must allow the exiting flotilla to clear the approach area. Thus, as with a fly lockage the mark for the start of lockage is further away from the lock.

The "state" variables, daytime, upriver, clearance under the sill, and month each have strong and statistically significant effects as well. Daytime and upriver lockages take less time. Daytime lockages pass through an estimated 6 percent faster than nighttime lockages; Upriver lockages pass through only an estimated 2 percent faster than downstream. Clearance under the sill represents water levels, sill depth, and depth of the flotilla. As clearance under the sill increases (water levels are higher), times fall. A one percent increase in clearance results in a .11 percent reduction in times. Alternatively, if the average clearance level is 10 feet, an increase of one foot reduces times by about 5 minutes. The final set of state variable reflects monthly dummies (not reported to conserve space), but generally, January has the fastest time, while November and December have the slowest times, given all else is the same.

TABLE 2 PARAMETER ESTIMATES

Variable	*Base*	*Lock FE*	*Lock&Vessel FE*
Double-Cut (Dummy)	0.748	0.751	0.760
	(164.48)*	(176.02)*	(166.48)*
Number of Barges (Log)	0.102	0.11	0.133
	(25.57)*	(29.22)*	(28.19)*
Tons per horsepower (Log)	0.062	0.059	0.068
	(36.42)*	(36.96)*	(39.1)*
Zero-tons (Dummy, all barges empty)	-0.022	-0.091	-0.086
	(-6.94)*	(24.94)*	(-23.36)*
Turnback lockage (Dummy)	-0.174	-0.196	-0.194
	(-74.25)*	(87.05)*	(-89.50)*
Exchange lockage (Dummy)	0	-0.024	-0.024
	-0.06	(10.96)*	(-11.25)*
Flotilla Length (Log)	0.284	0.27	0.174
	(38.83)*	(39.17)*	(21.42)*
Knockout, jackknife or setover lockage (Dummy)	0.182	0.191	0.211
	(32.77)*	(36.54)*	(38.58)*
Day-time lockage (Dummy)	-0.058	-0.056	-0.058
	(30.79)*	(31.86)*	(-33.91)*
Upriver lockage (Dummy)	0.019	0.017	-0.014
	(9.14)*	(8.69)*	(-7.22)*
Clearance (Log)	-0.116	-0.033	-0.027
	(-47.55)*	(8.80)*	(-7.29)*
% tanker barges (Level)	0.138	0.161	0.031
	(30.54)*	(37.76)*	(3.1)*
% other barges (Level)	0.003	-0.022	0.020
	(-0.006)	(3.82)*	(2.03)*
1200 foot lock (Dummy)	0.014	NA	NA
	(2.86)*		
400 foot lock (Dummy)	-0.38	NA	NA
	(-57.83)*		
500 foot lock	-0.008	NA	NA
	(-0.95)		
Intercept	1.876	1.561	2.422
	(44.34)*	(38.96)*	(27.07)*
R-squared	0.86	0.88	0.89

Notes: t-values are in (). A * and a ** indicate statistical significance at the 5 and 10 percent levels.

Lock fixed effects

Incorporated in the previous model is a set of dummies that represent the length dimension of a lock. There are a number of other possibilities. These include other dimensionality figures such as width and pool design lift (the vertical difference in adjacent pool design elevations), gate types. In principle, these reflect variables that are observed and could be integrated into the base model. However, there are a number of other variables for which measures are not so obvious. These include outdraft conditions, the ease of approach and exit, operator skills, differences in the recordation of data, the level of obsolescence, etc. For these effects, there is little in the way of data. Instead, the lock length variables are removed from the base model, and fixed effects for each lock are added to the model. A fixed effect captures systematic differences across locks that are the result of systematic differences across locks that are not captured in the model.

The results are reported in column 2 of Table 2. The fit of this model is improved from an R-square of 86% to 88% which is a statistically significant effect. The coefficients are relatively unchanged from the base model qualitatively, and generally, the qualitative results are about the same. There are a few differences. First, the coefficient on exchange lockages becomes statistically negative, although very small. This indicates modest faster times associated with exchange lockages relative to fly. However, the magnitude is considerably smaller than that of turnover (as expected). Second, clearance under the sill becomes much smaller in magnitude. This effect is still statistically negative, but the average value across locks appears to be considerably different and may be captured in the fixed effect terms.

The fixed effects can be used to identify locks that, *given all in the model*, are faster or slower than the base lock. These differences may capture omitted variables that differ systematically across locks. They may, for example, capture different approach, outdraft, data recordation, facility differences, differing levels of obsolescence, skills of operators etc. All of these sources are termed "efficiency" defined as effects not captured in the model. and efficiency. The base lock in the specification is the lock with the most lockages (lock 27). The values of the fixed effects (exponentiated) are in Figure 1. The values are interpreted as a multiplicative factor on the time of lock 27, *given all else in the model is the same*. Thus, a value of .88 means that the particular lock moves the same flotilla through the lock under the same "state" conditions, at 88 percent of the time that it would move through lock 27. From these results, there are notable differences across locks. The values range from .71for lock 51 up to 1.46 for lock 19. Generally, the Upper St. Anthony and Lock 1 have the fastest effects. However, but these do not handle the level of commercial traffic that the other lower locks do.

These measures have embedded in them "observed" effects. To isolate unobserved from observed effects, a "Saxonhouse" regression is performed. Specifically, the fixed-effects for all locks are regressed on observed characteristics. These include age, length, lift, a dummy for mooring facilities, and a dummy for the Minneapolis locks (51, 51, and 1). These locks report materially smaller values than the other locks, yet, their designs, tonnages, and traffic classes are much different. Because the dependent variable is a "generated" regressor, the variables are weighted by their respective standard errors. The result is:

$$\underset{}{dummy} = \underset{(-3.09)}{-2.88^*} + \underset{(4.82)}{0.22^*}\log(age) + \underset{(2.27)}{0.29^*}\log(length) + \underset{(2.06)}{0.096^*}\log(lift) - \underset{(-0.16)}{0.004}Moordum - \underset{(-2.23)}{0.269^*}MPLS$$

The overall fit of the equation is an R-square of 78% (on the weighted variables), but the correlation of the predicted value and the observed fixed effect is .9 (squaring this yields on R-square of .81 relative to the unweighted data). Thus, observed lock attributes explain 81 percent of the variation of lock effects from lock 27. Generally, the results are robust to alternative functional forms and variable inclusions. These results suggest that differences from lock 27 are explained by length, lift and age of locks, each of which increase times relative to lock 27. Interestingly, mooring facilities do not have a statistically important effect. Further, in other specifications, whether a lock underwent major rehabilitations was included with no significant effect.

The purpose of this exercise is to identify not only key structural designs that influence process times, but also to "clear" out the "observed" influences. That is, one interpretation of the difference between the predicted value and the observed (estimated fixed effect) is as an "efficiency" effect. From the regression, the efficiency measure is the predicted value minus the observed fixed effect. This difference for the locks is presented in Figure 2. It is noted that in this figure, higher levels of efficiency have higher values. The results suggest that locks 22 and 52 are less efficient than predicted, while locks 1, 10, 13 and 51 are more efficient than predicted. Of significant interest is the fact that lock 19, relatively slower than lock 27 above, is about as predicted by its observed effects.

The magnitudes of the effects require some explanation. That is, the scores in Figure 2 must be exponentiated to frame a comparison to lock 27. That is, the exponentiated values are multiplicative. A value of one means lockages are the same as in lock 27. The unobserved efficiency measures above relate to these multiplicatively. That is, a value near zero means that the multiplicative factor is not affected (i.e., $e^1 = 1$). The results suggest multiplicative factors that range from .87 to 1.11; A value of 1.11 means that the associated lock is 11 percent more efficient than implied by the observed effects, while a value of .87 means the lock is 13 percent less than implied by the observed effects.

Figure 1. Lock Fixed Effects Relative to Lock 27.

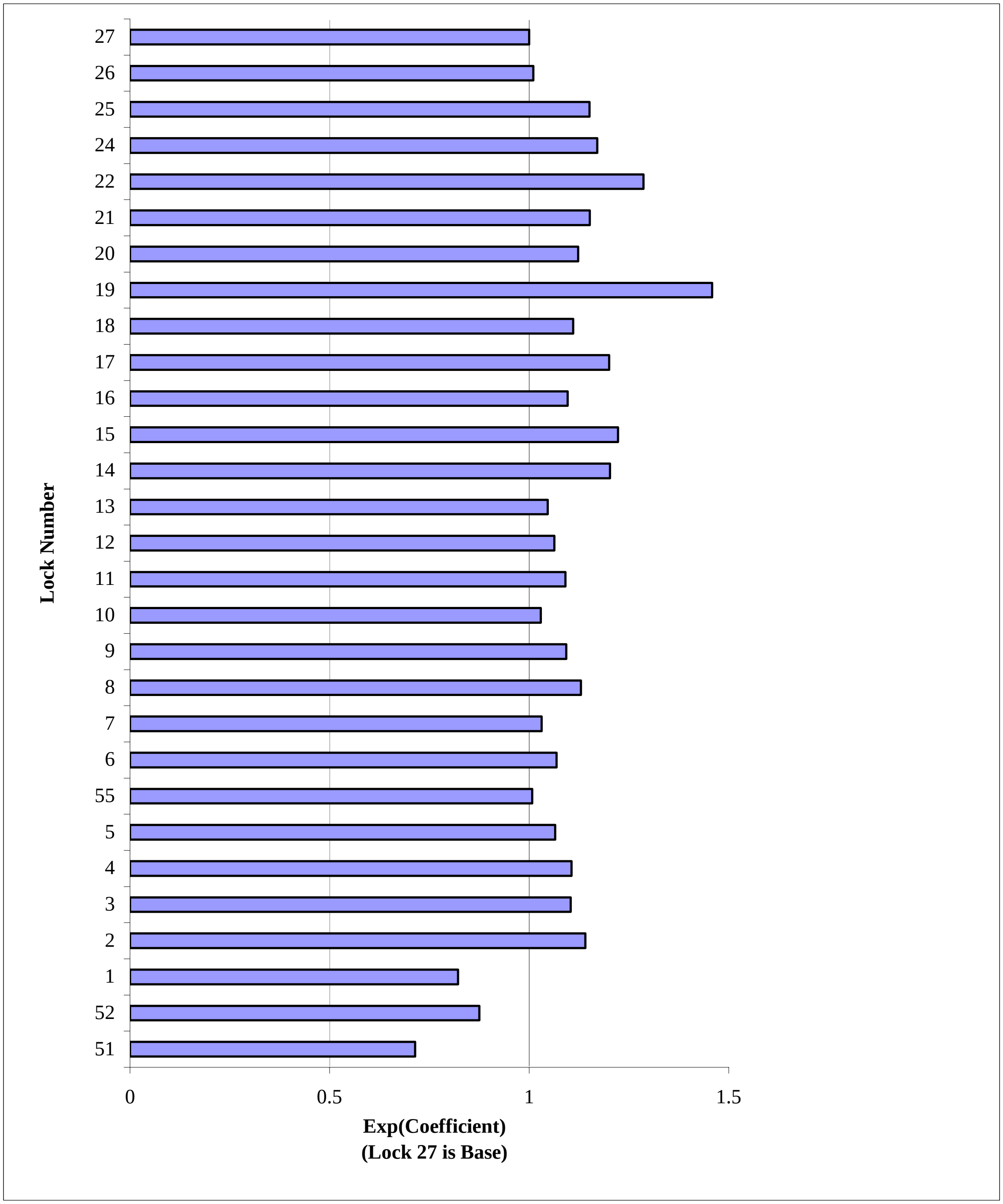
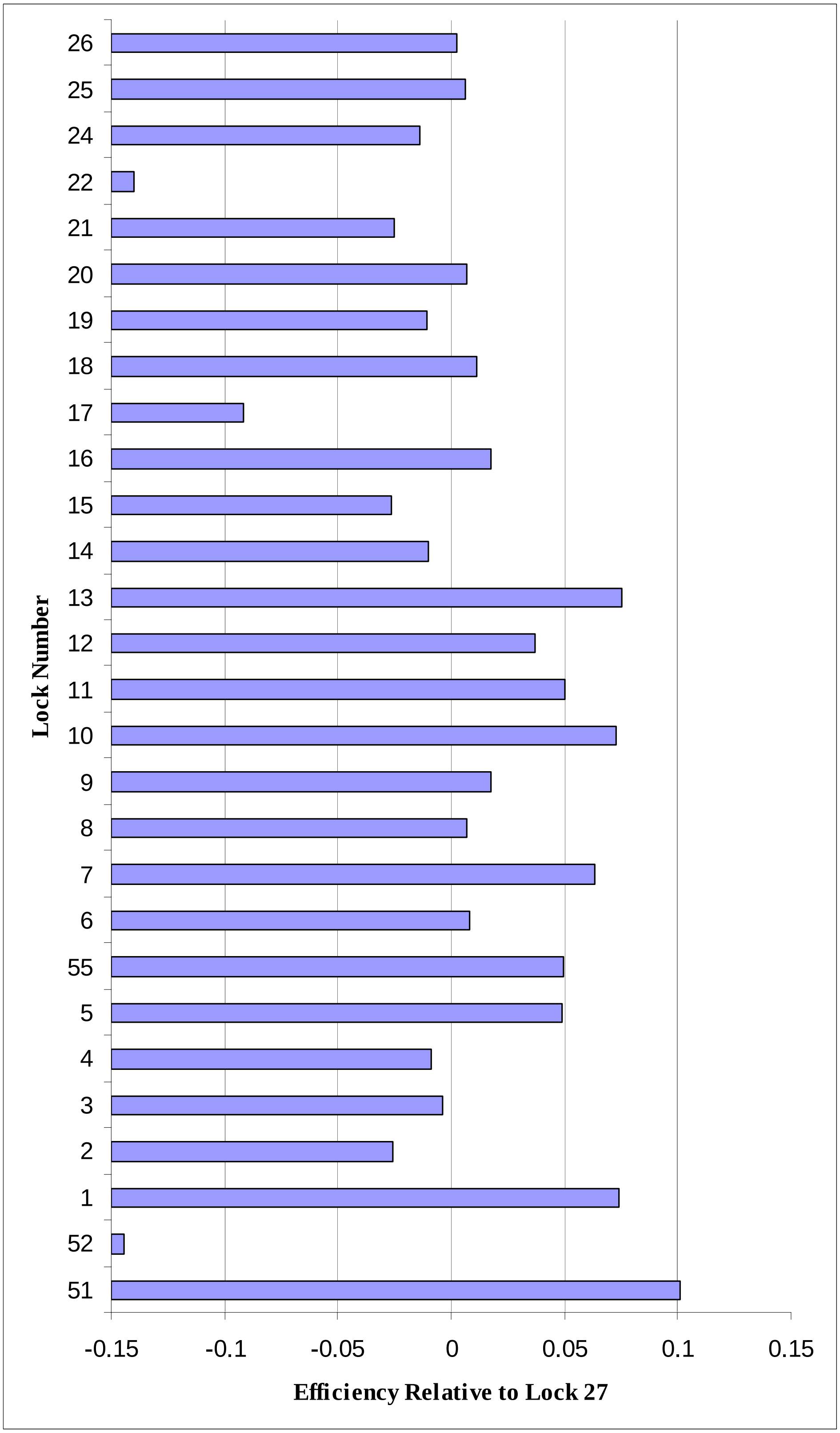


Figure 2. Unobserved Lock Efficiency Effects



Vessel Efficiency Measures

In this section, an analogous procedure to that of locks was performed for vessels. Most vessels operate across a number of different locks and even river systems. A fixed effects model for vessels can therefore be estimated and still retain the ability to include fixed effects for locks. Again, a fixed effect picks up any systematic differences across vessels and locks that are not represented by variables in the basic model. The results are in column 3 of Table 2 and yield almost identical coefficient estimates to the model with only lock fixed effects, and the discussion of the individual parameter effects is not repeated here.

The vessel fixed effects are presented in Figure 3. There is a wide range of values indicating significant differences across vessels in locking times, *controlling for all else*. The range of values is from -.45 to .59. These mean that the fastest vessel can transit locks at 63% of the base vessel, while the slowest vessel transits locks at 180 percent of the base vessel time. Suppose the base vessel with a single cut takes 50 minutes then these differences range for about 32 minutes to 90 minutes.

Vessels, however, come in all shapes and sizes, and these variables may influence transit times. Following the same procedure as in the previous subsection, a model of vessels is estimated. Vessels have a number of differing characteristics are observed, and several that are not. The variables included are the horsepower, height, length, breadth, draft (load draft), and age (measured by the number of years since it was built or rebuilty). Further, the number of lockages by the vessel (numlock) and a measure of the diversity of operations are included (diversity). Diversity was constructed like a Herfindahl Index as follows: For each vessel, the number of lockages at each lock was calculated and divided by the total number of lockages by the vessel. This share was then squared and the sum of these squares across the power vessel forms the measure. A value of one means that all lockages were at a single lock, while a number closer to zero means that the vessel was more "diversified". One might expect that as this measure increases (it is an inverse measure), the power vessel is more specialized and lock "capital" is greater with the result that transit times fall.

Two different specifications are estimated, and righthand variables in each are measured in logs. First, to control for "firm" effects, measures of overall firm size were included. These are the total number of lockages by firm and the total number of vessels operated. Second, instead of incorporating these variables as observed firm effects, a fixed effect model was estimated to capture differences across firms. The results of these two specifications are in Table 3. The overall fit in both models is quite high (.27 and .62) for models of this ilk. However, the statistically important effects in both models are consistent. However, the fixed effect model has clear dominance over the non-fixed effect specification. In this case, the number of lockages by a vessel has a strong and negative effect on the vessel effect and, therefore, on processing times. As the diversity measure increases (this means the vessel tends to operate at "fewer" locks, the vessel fixed effect falls and with it processing times. Interestingly, the vessel design features do not seem to have an effect once firm effects are captured. This may reflect that firms do not have a lot of variation in their fleets, and, therefore, the firm effects capture the vessel effects.

As a final exercise, the firm effects (that is, the unobserved variables captured in the firm effects) are presented in Figure 4. Again, these mark differences across firms in explaining power vessel effects which explain transit times. Large number means that the power vessel effect is stronger, and processings times are longer. The range of values is from -.41 to .53 which translate into multiplicative factors of .66 and 1.71. These mean that the faster firms move at .66 of the base firm times, and the slowest firms move at 1.71 of the base firms times. Suppose a lockage that takes a vessel by the base firm 50 minutes. The range of times by different firms is 33 minutes to 85 minutes. The result points to tremendous differences across firms in processing times.

Figure 3. Vessel Fixed Effects

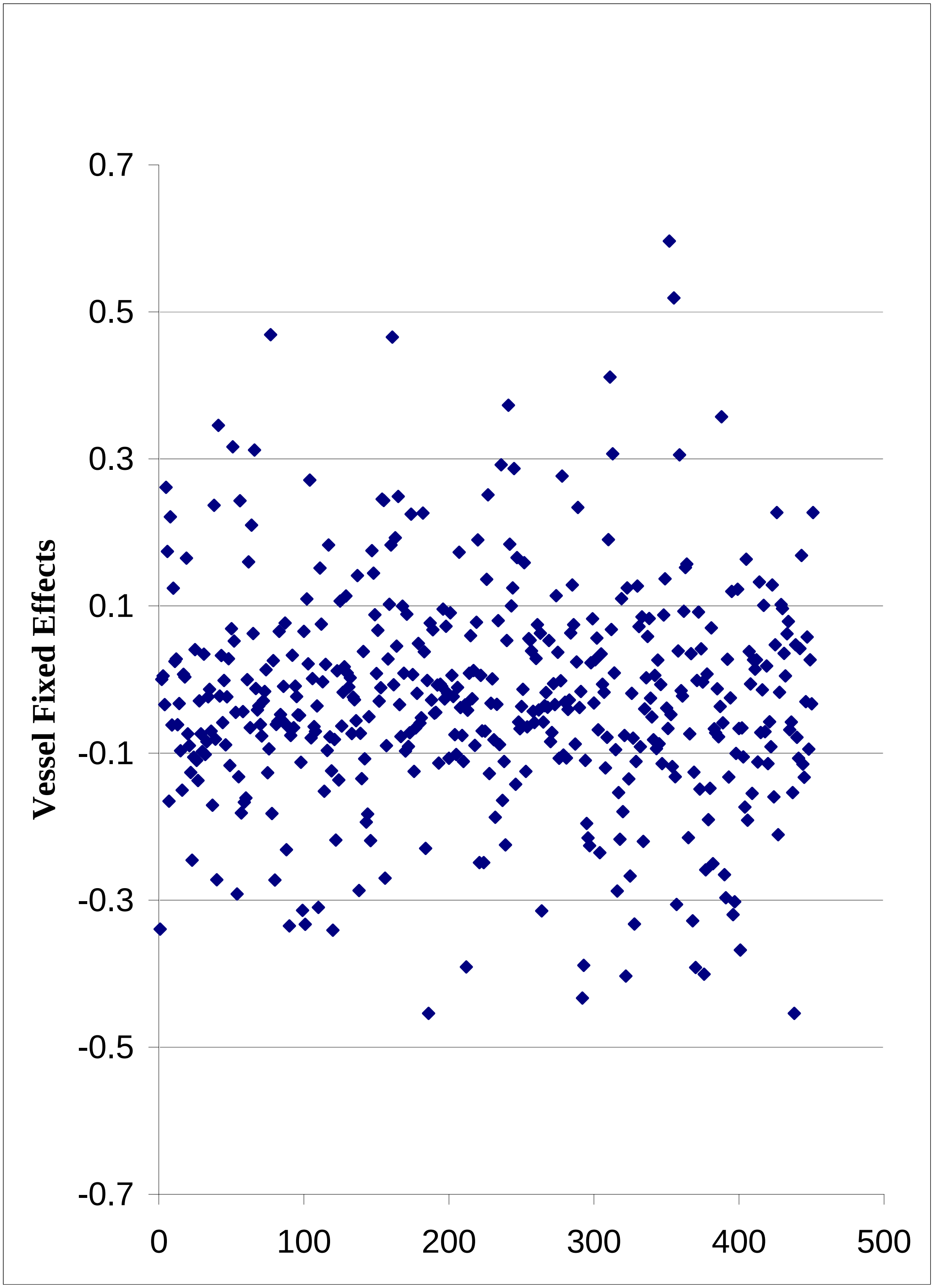
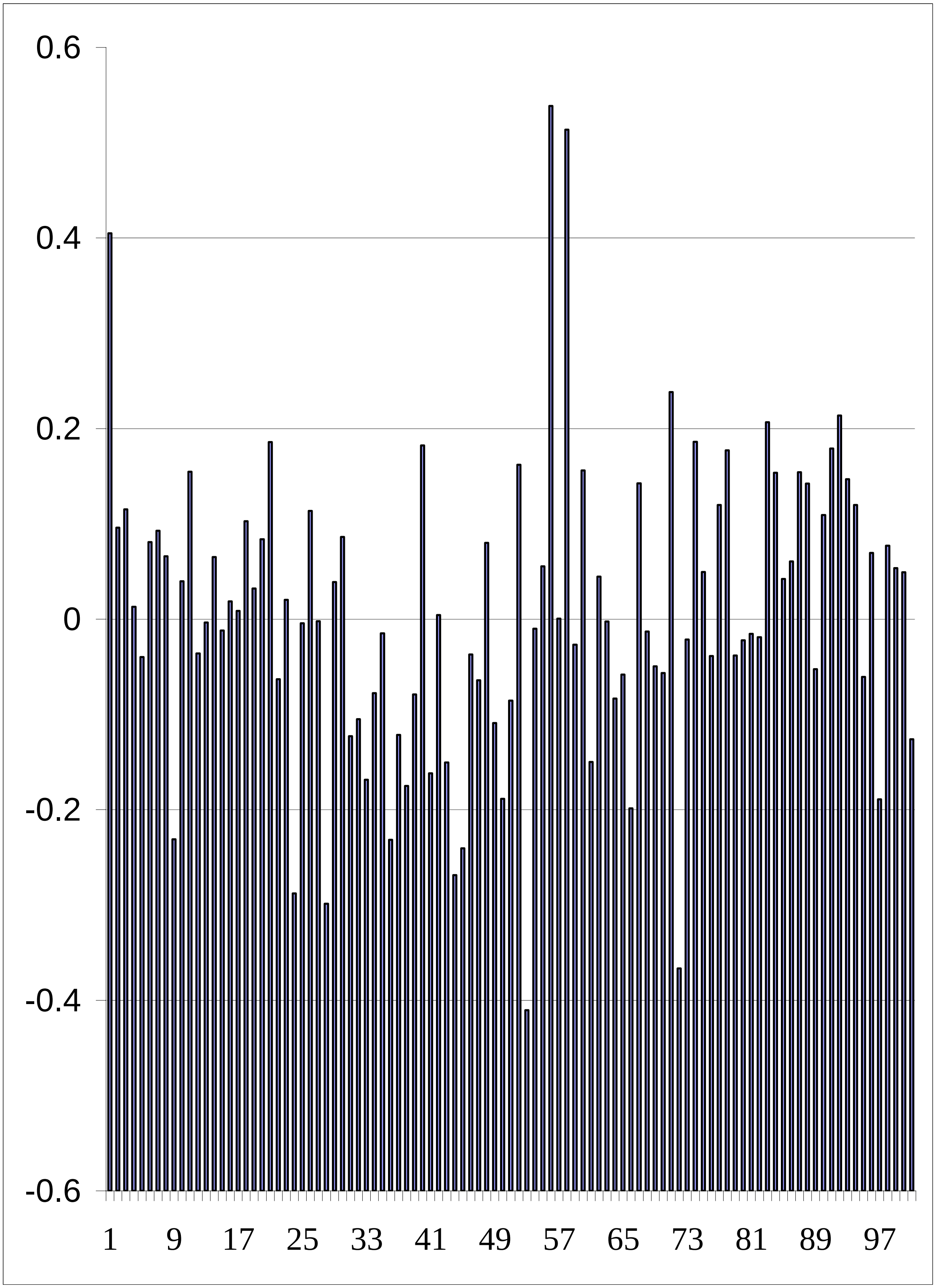


Table 3 Firm Effect Model Parameter Estimates

Variable	**No Fixed Effects**	**Fixed Effects**
HRP	0.041	0.016
	(1.80)	(0.68)
HFP	-0.056	0.005
	(-2.84)*	(0.27)
OVER_LNGTH	0.035	-0.022
	(0.88)	(-0.49)
LOAD_DRAFT	0.101	0.042
	(2.44)*	(0.92)
Age	0.004	-0.010
	(0.37)	(-0.66)
Numlock	-0.030	-0.016
	(5.30)*	(-2.89)*
Diversity	-0.035	-0.017
	(-5.04)*	(-2.18)*
Firm	-0.028	NA
	(-4.35)*	
Nvess	0.046	NA
	(4.82)*	
Constant	-0.408	
	(-4.24)*	-0.126
Observations	447	(-0.72)
R-squared	27	62

Figure 4. Firm Effects



SUMMARY

This paper provides a model of lock processing times. The results are consistent largely with expectations. That is, double lockages require more than twice the time as a single lockage. However, this study attempts to control for a wide range of factors that apply to both locks and vessels. The results suggest that while observed lock characteristics capture much of the variation in processing times, vessel information does not do as well. Indeed, most of the variation in vessel effects are do to firm effects. Uncovering the sources of firm effects represents an excellent area of future research.

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The centerpiece of these efforts will be a suite of simulation models. This suite will include:

- A model for forecasting international and domestic traffic flows and how they may be affected by project improvements.
- A regional traffic routing model that will identify the annual quantities of commodities coming from various origin points and the routes used to satisfy forecasted demand at each destination.
- A microscopic event model that will generate routes for individual shipments from commodity origin to destination in order to evaluate non-structural and reliability measures.

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