The Navigation Economic Technologies Program

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Market Adjustments over Transportation Networks

A Time Series Analysis of Grain Movements on the Mississippi Inland Waterway System

US Army Corps of Engineers®

IWR Report 05-NETS-R-06

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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MARKET ADJUSTMENTS OVER TRANSPORTATION NETWORKS

A Time Series Analysis of Grain Movements on the Mississippi Inland Waterway System

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Market Adjustments over Transportation Networks:

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by

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ABSTRACT

Transportation occurs over a network and involves a multitude of different origins, destinations, and modes. The estimation of structural network models are complicated by the disaggregate nature of markets and the lack of sufficient and/or consistently measured data. Yet, an understanding of the type and level of market adjustments is central to analyzing the effects of policy. In this paper, time-series techniques are used to characterize the relationship between river traffic and key economic variables for grain flows on the Upper Mississippi and Illinois Rivers. The model allows both modal and market substitution patterns to be evaluated. In addition, the model allows for dynamic relationships between key variables to be estimated. Estimation is conducted using a vector autoregressive model that includes six categories of variables. These are the number of barge lockages on the river, rail deliveries to major markets, rail rates, grain bids at major markets, ocean freight rates to primary importers from different export points, and barge rates to the Gulf of Mexico. We evaluate the interrelationships between these variables over time using impulse response functions. Variance decompositions are also constructed and are used to identify the most important variables affecting lockages and other variables in the model at both short and long horizons. Central findings of this study are that (i) barge demand shocks affect lockages positively, (ii) grain demand shocks affect rail deliveries and lockages positively, (iii) ocean freight demand shocks affect rail deliveries negatively, (iv) rail demand shocks affect rail deliveries and lockages positively, and (v) rail supply shocks affect lockages negatively.

1. INTRODUCTION

Theoretical and empirical analysis of transportation markets is an extremely complicated undertaking. Transportation markets are defined over a network involving multitudes of commodities, origins, and destinations. Trades are typically negotiated between heterogeneous demanders and suppliers of differentiated products that provide (or can provide) service to a multitude of different destinations. Theoretically, market adjustments to exogenous changes are non-trivial and result from a computable general equilibrium framework. Empirically, the analysis is compromised by a lack of sufficiently detailed data across the different modes and through the spatial environment. Yet, evaluation of market adjustments is central to policy evaluation. For example, the Army Corps of Engineers maintain the nation's waterways. The relationship between river traffic and economic variables such as modal and port prices play a key role in determining the potential benefits of waterway projects. In Army Corps planning models, these relationships are identified and examined using structural models. However, the National Research Council and others have noted a number of concerns with this approach. These concerns relate largely to assumptions regarding the structure of demand and the lack of representation of important substitution patterns across space, modes and alternative markets.[1] In this study, time-series techniques are used to model transportation market adjustments and substitution patterns across both modes and alternative markets.

The time-series model used in this paper allows the data to identify important patterns between the level of river traffic and the interrelationship with terminal prices,

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[1] For example, see "Inland Navigation System Planning: The Upper Mississippi River – Illinois Waterway" (2000) from the NRC and "Adequacy of Research on Upper Mississippi-Illinois River Navigation Project" (2000) by Berry, Hewings, and Leven for the Northeast-Midwest Institute.

barge rates, rail rates, rail deliveries, and ocean freight rates. In addition, the model is useful for understanding how river transportation is affected by shocks to barge prices as well as shocks to prices and quantities of products shipped down the river and prices and quantities of competing transportation modes. Further, demanders and suppliers of river transportation services often make decisions based upon future expectations of such variables and the model developed here is capable of uncovering such relationships over time. This is important because, as suggested by recent experience on the Mississippi, changes in variables such as ocean freight rates can have large and dramatic influences on river traffic and little is known about how these variables are related. Also, events such as unexpected lock closings can be captured within the model used here and the effects of such closures on prices and quantities of transportation services can be determined. Such information is useful not only to understanding the relevant patterns of substitution, but also to understanding the dynamic adjustments to key variables that can be used to frame transportation decisions.

Throughout the paper, the analysis is conducted using vector autoregressions (VARs). This approach is designed to partially address problems with traditional static and dynamic structural forecasting and modeling. Each approach has its merits and ought to be viewed as complementary.[2] As is well known, forecasts based upon structural models are often inadequate and inaccurate due to lack of knowledge

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[2] Most forecasting models of river traffic rely on structural modeling. Structural econometric models have behavioral equations, equilibrium conditions, and accounting identities derived from theoretical models as their basic building foundation. This results in restricted models, with the restrictions often in the form of the exclusion of some variables from some equations. Identification restrictions often result in further exclusions, often without theoretical support. Vector autoregressive models do not impose any exclusion restrictions upon the data; instead, they generally rely upon restrictions on contemporaneous causal relationships or assume zero long-run effects of particular types of shocks. Thus, in these models structural shocks are still identified, but through a different set of identifying assumptions that do not involve excluding variables from particular equations.

regarding the true structure and because of changes in structure not incorporated into the model. In the case of river transportation, structural models forecast the demand for river transportation from forecasts of the demand for products that use river transportation such as grains and industrial products.[3] These demands are then allocated to individual locations (a pool) on the river using historical patterns. Such an approach is a large and complicated task. The task requires simplifying assumptions that may be mandated by the lack of available sufficiently disaggregated data on commodity movements, and the lack of data on key demand variables. The difficulty of theoretical modeling of disaggregate markets together with the lack of sufficient data make econometric modeling of structurally defined network markets such as transportation exceedingly difficult. In this study, the pitfalls of structural modeling are avoided through the use of an approach common in time-series econometrics literature to understand the patterns of market adjustments in transportation markets, and, in particular, with respect to waterway transportation.[4] While this procedure identifies structural shocks by imposing restrictions on the variance-covariance structure associated with the reduced form model, recovery of the structural parameters themselves, and hence the demand curves, is not a feature of this estimation procedure. What the models do provide is a means of informing the future construction of dynamic structural models.

[3] Two examples are Baumel (2000) and Sparks Companies Inc. (2002).
[4] For in depth discussions of the advantages and disadvantages of the VAR versus structural approaches, see Anderson (1979), Sargent (1979), and Stock and Watson (2001).

2. TIME SERIES ANALYSIS

Economists commonly use time-series techniques to understand and forecast variables of interest. These models are used for forecast horizons that extend far into the future as well as for shorter horizons, as short as days or even minutes in the financial literature. Error correction and vector autoregressive (VAR) models are often used in this type of analysis. Formally, these models are interpreted as general reduced form structural models.[5] The models arise from the idea that the identification restrictions present in most structural econometric models are arbitrary and not supported by underlying theoretical models. If the identification restrictions used to estimate structural econometric models are suspect, then it is not surprising that these models do not produce reliable forecasts. An alternative is to rely on a different identification scheme and forego the troublesome identification restrictions present in structural econometric models.

This led researchers to consider VAR, and later error-correction models as an alternative to structural modeling. Under this approach, a very general reduced form is posited which allows each endogenous variable to depend upon every other endogenous variable in the model as well as any exogenous variables.[6] Estimation allows the data to impose restrictions as required to achieve the best fit. This is in contrast to the structural approach where such restrictions are imposed as maintained hypotheses. Forecasts of the endogenous variables can then be derived from the estimated time-series models. More importantly and central to this paper, once the model is estimated, it can be used to simulate the reaction of key variables to shocks (i.e. the response to positive

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[5] A seminal article in this area is Sims (1980).
[6] Thus, there are no exclusion restrictions as would exist under the structural approach.

orthogonalized innovations; the response to a negative shock would be the opposite) to other variables and produce estimates of how key variables are related (impulse response functions) and evaluate the importance of each variable (variance decompositions).

VAR and error-correction models are often called atheoretical models, but this can be misleading. The models are atheoretic in the sense that variables are not arbitrarily excluded from structural equations to obtain identification, and reduced forms rather than behavioral relationships are the focus of the modeling effort. However, identification assumptions are still required in order to identify structural disturbances, and the identification of structural disturbances is a necessary component in estimating and properly interpreting the impulse response functions and variance decompositions used in this paper. In the time-series literature, such restrictions are generally restrictions upon contemporaneous relationships, as in this paper, or restrictions regarding the long-run effects of particular shocks.

In previous work, De Vany and Walls (1996, 1999) demonstrate the usefulness of VAR models to quantify equilibrium dynamics over power and natural gas networks. As they note in their 1999 paper, the structure of networks is sufficiently complicated so as to preclude direct theoretical and empirical modeling of each and every relationship in each and every market, and the data requirements to do so are extreme, and the problems with modeling market adjustments in transportation market are the analogous. In such cases, theory can be used to guide the construction of VAR models, which can then be used to uncover network adjustments. As noted by DeVany and Walls:

> "To quantify power price dynamics on the WSCC network, we employ a flexible statistical model that allows us to characterize the joint distribution of power price changes with few a priori constraints. The statistical model – an unrestricted vector autoregression – encompasses the type of complex price dynamics that are

> characteristic of electrical networks, and this type of model has been used to quantify price dynamics in other network markets (De Vany and Walls 1996)."

In their 1996 paper, De Vany and Walls also note the usefulness of VAR models for capturing multilateral spatial relationships in power and natural gas networks

> "The sophistication of econometricians in quantifying the strength of spatial market linkages has increased in step with time-series methodology; however, the current statistical tests for market linkages consider only pairs of markets. In fact, most markets that are dispersed geographically contain many trading locations that are connected in different ways; some pairs have many paths between them whereas others are only indirectly linked."

To our knowledge, VAR and error-correction models have not been used to examine transportation networks even though the structural analysis of transportation markets share many, if not all, of the difficulties of structural modeling in other network industries, including those analyzed by Devany and Walls. The analysis in this paper focuses on grain transportation markets with a special focus on barge transportation on the Mississippi and Illinois rivers. Grain flows consist primarily of wheat, corn and soybeans to the Gulf, the Pacific Northwest, and a variety of different inland locations. The grain flows enter the river at a wide number of different locations, and there are a number of alternative markets for grain, some of which do not require barge movements. The wide number of entry points, alternative terminal markets, and modal alternatives require an excessive amount of data not all of which are available, and the underlying equilibrium structure is exceedingly complex. Because of this, most previous models examining transportation market adjustments resort to either to a focus on a narrow set of markets or commodities, or to simulation models somewhat like the Army planning models discussed earlier. Indeed, there are few studies that model transportation equilibria theoretically or empirically.[7]

In the next section, a time-series model is constructed and the available data described. The model contains data for movements of multimodes, transportation rates, prices of commodities at spatially separated markets, and ocean freight rates. Each of these variables has some relation to the underlying formal structural model, and as such, are important variables to include in the model. More specifically, the model consists of lockages on the Mississippi river, rail deliveries of grain to export points, rail rates for grain to export points, the bid price for grain at export points, ocean freight rates from export points, and barge rates on the Mississippi river. The first two categories, lockages and rail deliveries, involve quantities while the last four, rail rates, grain bids, ocean freight rates, and barge rates, involve prices.

The model developed here is used to produce impulse response functions and variance decompositions. These show how particular variables in the model respond to unexpected changes in other variables in the model, and how important each type of shock is in explaining variance of the variables in the model. The central results of both the impulse response functions and variance decompositions are that (i) barge demand shocks affect lockages positively, (ii) grain demand shocks affect rail deliveries and lockages positively, (iii) ocean freight demand shocks affect rail deliveries negatively, (iv) rail demand shocks affect rail deliveries and lockages positively, and (v) rail supply shocks affect lockages negatively.

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[7] Wilson, Wilson, and Koo (1988) estimate a structural supply and demand model for rail and truck markets for a narrowly defined market, i.e. grain transportation of North Dakota origins. Friedlaender and Spady (1981) estimate supply and demand models separately, then combine them to simulate outcomes of rail and truck markets.

3. DATA AND ECONOMETRIC MODEL

The time-series model and associated impulse response functions and variance decompositions are constructed as follows.

First, data on river traffic through each lock and prices of commodities from various geographic regions are obtained from the Lock Performance Monitoring System (LPMS) as reported in the USDA's *Grain Transportation Report*. Commodity price and other data are also in the USDA's *Grain Transportation Report* which is available on a weekly basis. The nineteen variables available for use in the analysis are shown in Table 1. The data are available consistently from the first week of 1999 through the 20th week (the last week of May) of 2003.[8]

There are six categories of variables in the table, lockages, rail deliveries, rail rates, grain bids, ocean freight rates, and barge rates. Within each category the variables are highly collinear, and nineteen variables is a relatively large number for the type of analysis used here, so representative variables from each category are used in the model. These data are used, in customary log form, in a six variable time-series model. In particular, the variables are the log of lockages at Mississippi lock #27 (located near St. Louis, Figure 1), the ratio of grain deliveries by rail to the Gulf of Mexico to grain deliveries by rail to the northwest, the ratio of the rail delivery rate from Kansas City to the Gulf of Mexico to the rail delivery rate from Kansas City to Portland, the ratio of the price of wheat in the gulf to the price of wheat in Portland, the ratio of the ocean freight rate from the gulf to Taiwan to the ocean freight rate from Portland to Taiwan, and the

[8] While these data have been collected for a longer time period, the variables are not consistently measured throughout the sample period, and in some cases are only available for a sub-period, limiting the extent of the sample.

barge rate from St. Louis to Cairo. Graphical representations of each of the variables used are provided in Appendix A.

The order of the variables in the VAR model is the same as in the table, lockages, rail deliveries, rail rates, grain prices, ocean freight rates, and barge rates. Weekly dummies are added as deterministic variables to capture any seasonal effects over the year. For example, the first equation of the VAR model is Total Lockages on the Mississippi at Lock #27 regressed upon a constant, the weekly dummies, and lags of each of the six variables in the model.[9] The second equation is the ratio of rail deliveries regressed upon the same set on independent variables, a constant, the weekly dummies, and lags of each of the six variables in the model, and so on, until the last equation which has the St. Louis to Cairo barge rate as the left-hand side variable.

Before proceeding, the time-series properties of the individual series, in particular the stationararity or unit root properties, as well as any co-integrating relationships that might exist among the variables, are examined. However, before these tests can be performed, the lag structure of the variables needs to be determined.

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[9] The variables shown in the table are Total Lockages on the Illinois at Lock #8, Total Lockages on the Mississippi at Lock #15, Total Lockages on the Mississippi at Lock #27, Rail Deliveries to Texas, Rail Deliveries to Mississippi, Rail Deliveries to the Pacific, the Tariff Rail Rate for Wheat from Kansas City to Houston, the Tariff Rail Rate for Wheat from Kansas City to Portland, the Bid Price for Portland HRW, the Bid Price for Gulf HRW, the Bid Price for Gulf SRW, the Bid Price for LA Corn, the Gulf to Taiwan Ocean Freight Rate for Heavy Grain, the PNW to Taiwan Ocean Freight Rate for Heavy Grain, the Barge Rate for the Mid-Mississippi (Percent of Tariff from Davenport IA), the Barge Rate for the Illinois (Percent of Tariff for the Illinois River, Peoria, IL), the Barge Rate for St. Louis-Cairo (Percent of Tariff from St. Louis) , the Barge Rate for Lower Ohio (Percent of Tariff from Lower Ohio) , and the Barge Rate for Cairo-Memphis (Percent of Tariff from Cairo). The six variables used in the model, the log of lockages at Mississippi lock #27, the ratio of grain deliveries by rail to the Gulf of Mexico to grain deliveries by rail to the northwest, the ratio of the rail delivery rate from Kansas City to the Gulf of Mexico to the rail delivery rate from Kansas City to Portland, the ratio of the price of wheat in the gulf to the price of wheat in Portland, the ratio of the ocean freight rate from the gulf to Taiwan to the ocean freight rate from Portland to Taiwan, and the barge rate from St. Louis to Cairo, are derived from these data.

Table 2 presents the Akaike information criterion (AIC) for lag length for each variable in the model. For all variables except the grain price ratio, one or two lags are selected by the AIC. For the grain price ratio, the number of lags selected is five.

The next steps involve the use of unit root tests to determine if the variables in the model are stationary or contain unit roots. These are presented in Table 3. It is not expected that the variables that are ratios will contain unit roots as the prices should move together in the long-run. The main concern is to check for unit roots in the non-ratio variables, lockages and barge rates. The tests are conducted using augmented Dickey-Fuller tests with the lag lengths determined by the AIC tests in the previous table.

For all variables except the grain price ratio, a two-lag model in levels is implied by these two tables. Thus, for these variables, a two lag VAR model in levels is implied. However, the tests also imply that the grain price ratio requires five lags and appears to contain a unit root, though the low power of unit roots tests with the span of the sample used here is noted as this undermines certainty regarding the presence of a unit root. In the VAR model used below, which uses the same number of lags for each variable, a two lag levels specification is assumed. But, because of the outcome of the tests in these two tables, several versions of the model are examined to ensure that this assumption does not affect the conclusions.[10]

In order to identify structural shocks in the model, the disturbances must be orthogonalized. The orthogonolization of the shocks in the model is performed in the usual manner using the Choleski decomposition. With this decomposition, the variables least likely to be affected by contemporaneous shocks to other variables come first in the

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[10] In particular, the variable was entered in both differences and levels, the variable was dropped entirely, longer lags for the VAR model were all examined, and none of which affected the conclusions meaningfully. In addition, system-wide lag tests supported the specification used here a well.

ordering and those variables most likely to be affected contemporaneously are placed last. Note that quantities appear in the model ahead of prices so that the identification assumption used here is the quantity supplied responds with at least a one period lag to changes in demand. That is, during the period of the shock, the supply curve is vertical so that any changes in quantity arise solely from shocks to the supply curve, but after one week supply can respond to the change in demand. Prices, however, respond to both supply and demand shocks since a shift in supply or demand will change the equilibrium price. Under this assumption, shocks in the model associated with quantities (i.e. the first two of equations for lockages and rail deliveries) can be interpreted as supply shocks (i.e., rightward shifts of supply) and those with prices (i.e. the last four of equations) as demand shocks (i.e., rightward shifts of demand).

The model is estimated using the data described above and the estimated model is used to produce impulse response functions (IRFs) and variance decompositions (VDCs). The IRFs show the impact that an unanticipated structural shock to one variable has on the time path followed by another. For example, an IRF can plot the effect that a shock in the barge rate between two points has on the amount of traffic through a lock. In the model, a shock to barge rates emanates from a rightward shift in the barge demand function. Such a shift should increase rates (or, at least, not decrease rates), and therefore, should increase lockages. Because a shock to any one variable can affect all other variables, there are (6)(6)=36 impulse responses. The complete set is available in Appendix B. The discussion below focuses on a subset of the responses, those with notable effects. The VDCs complement the IRFs. The IRFs show the pattern of the response over time of one variable brought about by a structural shock to another variable. The VDCs assess the importance of the shock in explaining the variance of the responding variable at each point in time. Thus, the IRFs give the sign and the pattern of the response while the VDCs assess the importance of the structural shock in explaining the variability of a particular variable at each point in time after the shock occurs.

4. IMPULSE RESPONSE FUNCTIONS

There are six variables in the model, lockages, rail deliveries, rail rates, grain bids, ocean freight rates, and barge rates. In the following, it is important to recall that IRFs for shocks to quantities (lockages and rail deliveries) reflect supply shocks e.g., a shock to barge lockages is a rightward shift in the supply of barge lockage services. Shocks to prices (rail rates, grain bids, ocean freight rates, and barge rates) reflect demand shocks under the identification scheme used in the estimation. Thus, for example, a shock to the barge rate represents a rightward shift in barge demands. In the subsections below the IRFs are first presented for quantity shocks and then price shocks. Interestingly, shocks to the supply of lockages do not point to appreciable effects, while shocks to rail supply do. Further, the effects of the price shocks tend to be much stronger. Each are discussed below.

A. Shocks to Total Lockages

Lockages are subjected to a shock of approximately 18%.[11] As discussed above, this is a supply shock, a rightward shift in the supply function of lockages. While the theoretical evaluation of all possibilities is not provided, a few examples may be useful. First, the effect of a lock supply shift should decrease or, at least, not increase barge rates. It should reduce or, at least not increase, both rail rates and quantities. Similar relations

[11] The size of the shock in all cases is one standard deviation. This is customary.

can be established for the other variables in the model. In the estimation results, however, none of the IRFs suggest an appreciable response to lockage shocks. Thus, because the impulse here is a shock to the supply of lockages, this variable does not have a substantial effect on the other variables in the model.

B. Shocks to the Rail Delivery Ratio

The next example is a supply shock to rail deliveries, in particular a shock of approximately 14% to the rail deliveries ratio. This shock is a supply shock to the supply of rail to the Gulf relative to the Pacific Northwest. As shown in Figures 2a, this shock points to a strong response. That is, an increase in the supply of rail services causes a decline in lockages which persists over many weeks. Thus, a supply shock to rail services causes a substitution away from barge services through lock #27. A mechanism to bring this about would be a fall in the rail price from a rightward shift in the rail supply function. This fall induces a substitution from river traffic. It is noted, however, that there is no appreciable change in the price of rail services evident in the IRFs. Recall, that the rail rates are tariff rates. These do not change a lot over the time period, but there are many other types of rail rates (e.g., shuttle train, secondary market rates, etc.) that are not in the model which may capture these adjustments better and may reflect an alternative mechanism through which the substitution occurs may operate, thus, implicit prices may change even though the posted price does not.[12]

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[12] Again, the development of time series is complicated by the fact that the particular origins-destinations-modes variables are not always constant through time in the data source used. Further, such data are not available elsewhere.

C. Shocks to the Tariff Rail Rate Ratio

Figures 3a and 3b depict the responses of a shock to the rail rate ratio. Recall, as this model is set up, such a shock reflects a rightward shift in the demand for rail. The responses show an interesting pattern. After the shock to the demand for rail services, rail deliveries and lockages both rise for three or four weeks, then return to the initial value after approximately ten weeks. The rise in lockages is due to the substitution towards barge services arising from the increase in rail rates. The rise in quantities is consistent with the expected response to a demand shock.

D. Shocks to the Grain Bids Ratio

The next set of IRFs reflect the responses of the variables to shocks in the grain bid ratio. These reflect rightward shifts to the demand for grain in the Gulf relative to the Pacific Northwest. Intuitively, these should increase the quantities to the Gulf. Figures 4a and 4b present the response of quantities and prices to a shock in the relative bids of approximately 1%. The two strongest responses to the demand shock for grain, those for lockages and rail deliveries. These are shown in Figures 4a and 4b. Figure 4a shows that the result of the shock is an increase in lockages that peaks at around 4 weeks and declines slowly thereafter. As shown in Figure, rail deliveries follow a similar pattern. That is, an increase over a four week period, and then declining slowly in subsequent weeks. These results point strongly to the relationship of port prices in the structural demands for rail and barge.

E. Shocks to the Ocean Freight Rate

Figures 5a and 5b examine responses to a demand shock for ocean freight deliveries of lockages and rail deliveries, and after a brief decline, the responses indicate an increase in quantities, as expected in response to a demand shock. However, the responses are fairly muted. These suggest ocean demand shocks have only a limited effect on both lockages and rail deliveries.

F. Shocks to the Barge Rate Ratio

The final example examines impulse response to a demand shock for barge services resulting in an increase in the barge rate. Figures 6a and 6b show the responses of lockages and rail deliveries to a 1% increase in the barge rate from a demand shock. In the model, this is a rightward shift in the demand for barge services. The results suggest there is a large and sustained increase in lockages as shown in figure 6a. The peak response occurs at around four or five weeks. This result provides evidence of a non-fixed demand structure for river traffic. The effect of a barge services demand shock to rail is in figure 6b. There is an initial decline in rail deliveries as expected. Over several weeks, the effect dies out and even becomes positive; a finding consistent with congestion feedback. This effect, however, is extremely small.

5. VARIANCE DECOMPOSITIONS

Impulse response functions document how variables in the model respond over time to their own shocks and to shocks to other variables. However, impulse response functions do not reveal how important the shocks are in explaining variation in the variable under consideration. For example, Figure 6a shows how lockages respond to a shock to the barge rate ratio at various time horizons up to one year after the shock. But among all six shocks identified in the VAR system, how important is this particular shock in explaining variation in lockages at these time horizons? Does a shock to the barge rate ratio cause more or less variation in lockages than, say, a shock to rail deliveries? Variance decompositions (VDCs), presented in Table 4, can be used to assess these questions.

A. Variance Decompositions for Lockages

Variance decompositions provide a delineation of the variance of a particular variable, say lockages, at each forecast step (from one to fifty-two in the figures) into the fraction of the variance attributable to shocks to each of the other variables in the model. The first set of numbers in Table 4 present variance decompositions for the lockage variable at steps of 1, 2, 4, 8, 12, 20, 26, 40, and 52.

Two main conclusions emerge from examination of the VDCs. First, the largest factor affecting the variance of lockages is shocks to lockages. This is not an unusual outcome for VDCs, i.e. that the largest fraction of the variability at all horizons is explained by a variable's own shocks. Second, setting aside the fraction of the variance of lockages explained by shocks to lockages, ocean freight rates explain the largest fraction of the variance, 7%, at the 52 week horizon, an effect the rises slowly over time. Third, in the initial few weeks, up until four weeks after the response, there is very little influence by any variable other than its own past. Finally, the combined amount of influence by rail deliveries, rail rates, and grain bids is 9% and this too is an effect that rises slowly over time.

B. Variance Decompositions for Rail Deliveries

The rail delivery ratio is in that the short-run rail deliveries are fairly exogenous, but as time passes grain bids begin to have an influence reaching 10% at 52 weeks. The second largest influence comes from rail rates, and there is a small influence from both lockages and ocean rates but the response is very small. The notable feature is the short-run exogeneity of rail deliveries, and the rising influence of grain bids and rail rates over time which account for 14% of the variation at the 52 week horizon.

C. Variance Decompositions for Rail Rates

The third set of numbers in Table 4 shows the VDC for the rail rate ratio. In the short-run, lockages play the largest role, explaining 4% at the one week horizon, followed closely by rail deliveries at 1%. Thus, changes in quantity variables caused by supply shocks explain most of the variation at this horizon. As the horizon is increases, the quantity variables become less important, and changes in price variables due to demand shocks become more important so that, at the 52 week horizon, lockages and rail deliveries explain 19% of the variation, and prices explain 31% with grain bids at 13%, ocean rates at 7%, and barge rates at 11%.

D. Variance Decompositions for Grain Bid Prices

Interestingly, the results indicate short-run feedback in the other direction, from lockages to grain bids, but the effect is fairly small at 2% at the one week horizon and 5 at the four week horizon. More influence in variation in grain bids comes from rail rates according to the results, but as in the previous cases, the effect is delayed and only appears after many weeks have passed. At the 52-week horizon, 14% is explained by rail rates, and lockages and rail deliveries combine to explain another 7%.

E. Variance Decompositions for Ocean Freight Rates

The variance decompositions for ocean freight rates again indicate that in the short-run most variability is due to its own past rather than the other variables in the model However, as time passes, as in previous cases, the effect of rail rates on ocean freight rates rises reaching 25% at the 52 week horizon. The effect of other variables is relatively minor in comparison, and their combined effect of 11% at the 52-week horizon is less than half as large.

F. Variance Decompositions for Barge Rates

Barge rates appear to be “fairly exogenous” in the short-run, i.e. the contemporaneous correlations are small. Thus, it is explained largely by its own past in the short-run, while other variables only have a small effect. Over time, however, as with the other decompositions, the effect of other variables rises. In particular, the effect of rail on deliveries comes in at 9% at the four week horizon and rises to 11% at the 52 week horizon. Rail rates and grain bids begin to have explanatory power at the 12-20 week horizon and rise to a combined 45 % (14% for rail rates and 31% for grain bids) at the 52 week horizon.

6. CONCLUSIONS

Transportation markets involve the movement of specific commodities between a multitude of origins and destinations by a variety of modes or combination of modes. Important demand drivers include the prices of the commodity transported and, in international markets, ocean freight rates. Econometric analysis based structural models are complicated by the complexity of the interrelationships and by the lack of sufficiently detailed and consistent data across modes. This paper overcomes the structural modeling problem by using complementary time-series techniques, and overcomes the data problem by focusing on key variables implied by the structure. In particular, impulse response functions and variance decompositions are used to characterize relationships among six variables (many ratios of two variables to capture relative effects) in a VAR model designed to trace the interconnections among variables in the model. The model contains six categories of variables, lockages, rail deliveries, rail rates, grain bids, ocean freight rates, and barge rates and looks at both short and long horizons.

The results show that most of the variables examined are fairly exogenous in the short-run, i.e. over the period of approximately four weeks. However, at longer horizons other variables begin to exert an influence so that the longer-run results are more interdependent. Central findings of this study are that (i) barge demand shocks affect lockages positively, (ii) grain demand shocks affect rail deliveries and lockages positively, (iii) ocean freight demand shocks affect rail deliveries negatively, (iv) rail demand shocks affect rail deliveries and lockages positively, and (v) rail supply shocks affect lockages negatively.

The results are consistent with the notion that quantities adjust to demand shocks in the barge, rail, ocean freight, and grain markets. Each of these demand side effects is consistent with the claims of various National Research Council reports and others on the treatment of demand in the various Army Corps planning models. Additional research is mandated, and, indeed attempts to measure the structural demand relationships and equilibrium responses that need to be reflected in planning models are currently underway.

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TABLE 1 Weekly Data from 1999:01 through 2003:20 Collected from the USDA's Grain Transportation Report Used in the VAR Model

A. Lockages

Total Lockages on the Illinois at Lock #8
Total Lockages on the Mississippi at Lock #15
Total Lockages on the Mississippi at Lock #27

B. Rail Deliveries

Rail Deliveries to Texas
Rail Deliveries to Mississippi
Rail Deliveries to the Pacific

C. Tariff Rail Rates

The Tariff Rail Rate for Wheat from Kansas City to Houston
The Tariff Rail Rate for Wheat from Kansas City to

D. Grain Bid Prices

The Bid Price for Portland HRW
The Bid Price for Gulf HRW
The Bid Price for Gulf SRW
The Bid Price for LA Corn Portland

E. Ocean Freight Rates

The Gulf to Taiwan Ocean Freight Rate for Heavy Grain
The PNW to Taiwan Ocean Freight Rate for Heavy Grain

F. Barge Rates

Barge Rates for the Mid-Mississippi (Percent of Tariff from Davenport IA)
Barge Rates for the Illinois (Percent of Tariff for the Illinois River, Peoria, IL)
Barge Rates for St. Louis-Cairo (Percent of Tariff from St. Louis)
Barge Rates for Lower Ohio (Percent of Tariff from Lower Ohio)
Barge Rates for Cairo-Memphis (Percent of Tariff from Cairo)

Table 2: Akaike Information Tests for Lag Length

	Lag Length Selected by AIC
MISS27	1
RAILDEL	2
RAILRATE	1
GRAINPRICE	5
OCEANRATE	2
BARGERATE	2

Table 3: Augmented Dickey-Fuller Unit Root Tests

	AR Model with Constant and Trend	AR Model with Constant
MISS27	-5.74474	-5.69993
RAILDEL	-4.17093	-3.83966
RAILRATE	-2.76941	-2.86990
GRAINPRICE	-2.34936	-0.99608
OCEANRATE	-2.93297	-2.76668
BARGERATE	-3.58555	-3.56752

Note: The critical values for the first two columns are –4.00, -3.43, and –3.14 for the 1%, 5%, and 10% levels of significance. For the second two columns the critical values are -3.46, -2.87, and -2.57. A single * indicates significant at the 10% level, ** indicates 5%, and *** indicates 1%. The number of lags is determined by Table 2. All variables are seasonally adjusted.

TABLE 4 Variance Decompositions

Lockages

Step	River Locks	Rail Deliv.	Rail Rates	Grain Bids	Ocean Rates	Barge Rates
1	1.00	.00	.00	.00	.00	.00
2	.99	.00	.00	.00	.00	.00
4	.96	.01	.01	.01	.01	.00
8	.90	.02	.03	.02	.03	.00
12	.88	.03	.03	.02	.04	.00
20	.85	.03	.03	.03	.06	.00
26	.84	.03	.03	.03	.07	.00
40	.83	.03	.03	.03	.07	.00
52	.83	.03	.03	.03	.07	.00

Rail Deliveries Ratio

Step	River Locks	Rail Deliv.	Rail Rates	Grain Bids	Ocean Rates	Barge Rates
1	.00	1.00	.00	.00	.00	.00
2	.00	.98	.01	.01	.00	.00
4	.00	.95	.02	.02	.01	.00
8	.01	.91	.03	.04	.01	.00
12	.01	.88	.03	.06	.01	.00
20	.02	.86	.03	.07	.01	.00
26	.01	.85	.04	.09	.01	.00
40	.02	.84	.04	.10	.01	.00
52	.02	.84	.04	.10	.01	.00

Rail Rate Ratio

Step	River Locks	Rail Deliv.	Rail Rates	Grain Bids	Ocean Rates	Barge Rates
1	.04	.01	.95	.00	.00	.00
2	.04	.05	.90	.00	.01	.01
4	.05	.10	.81	.01	.04	.01
8	.06	.14	.68	.00	.08	.03
12	.06	.15	.61	.01	.09	.06
20	.06	.15	.56	.03	.09	.10
26	.06	.15	.54	.05	.08	.11
40	.05	.15	.51	.10	.08	.11
52	.05	.14	.49	.13	.07	.11

Grain Bid Ratio

Step	River Locks	Rail Deliv.	Rail Rates	Grain Bids	Ocean Rates	Barge Rates
1	.02	.01	.00	.96	.00	.00
2	.04	.00	.00	.95	.00	.00
4	.05	.00	.02	.92	.00	.00
8	.06	.00	.05	.88	.00	.00
12	.06	.01	.08	.85	.00	.00
20	.05	.01	.11	.82	.00	.00
26	.04	.02	.12	.81	.01	.00
40	.04	.02	.13	.79	.01	.00
52	.04	.03	.14	.79	.01	.00

Ocean Freight Ratio

Step	River Locks	Rail Deliv.	Rail Rates	Grain Bids	Ocean Rates	Barge Rates
1	.00	.00	.01	.00	.99	.00
2	.01	.01	.03	.00	.95	.00
4	.01	.02	.10	.00	.87	.00
8	.01	.02	.21	.00	.75	.00
12	.02	.03	.25	.00	.70	.00
20	.02	.04	.25	.00	.67	.01
26	.02	.04	.25	.01	.67	.02
40	.02	.04	.25	.02	.65	.02
52	.02	.04	.25	.03	.64	.02

Barge Rate

Step	River Locks	Rail Deliv	.Rates	Grain Bids	Ocean Rates	Barge Rates
1	.00	.00	.01	.00	.02	.96
2	.00	.05	.01	.00	.01	.92
4	.01	.09	.02	.00	.01	.87
8	.01	.11	.03	.02	.00	.82
12	.01	.12	.05	.05	.00	.76
20	.01	.12	.09	.12	.00	.65
26	.01	.12	.11	.17	.00	.58
40	.01	.12	.13	.27	.00	.47
52	.01	.11	.14	.31	.01	.42

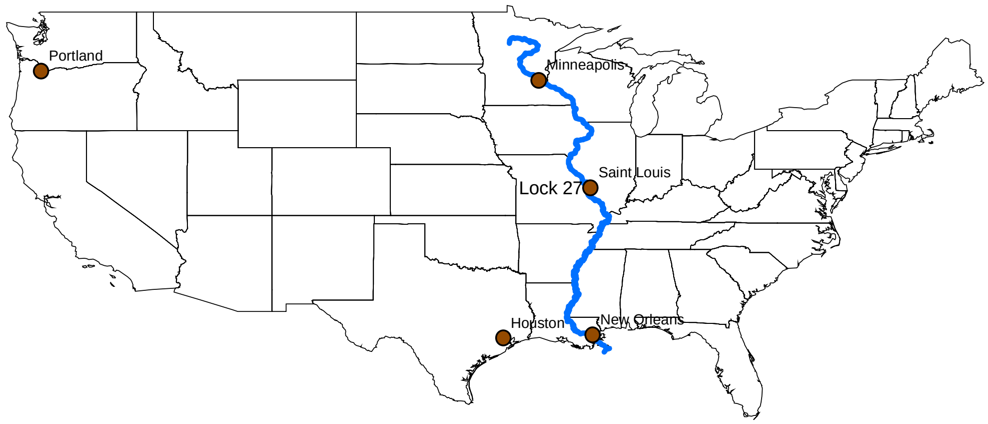


FIGURE 1 Lock #27 on the Mississippi Waterway System

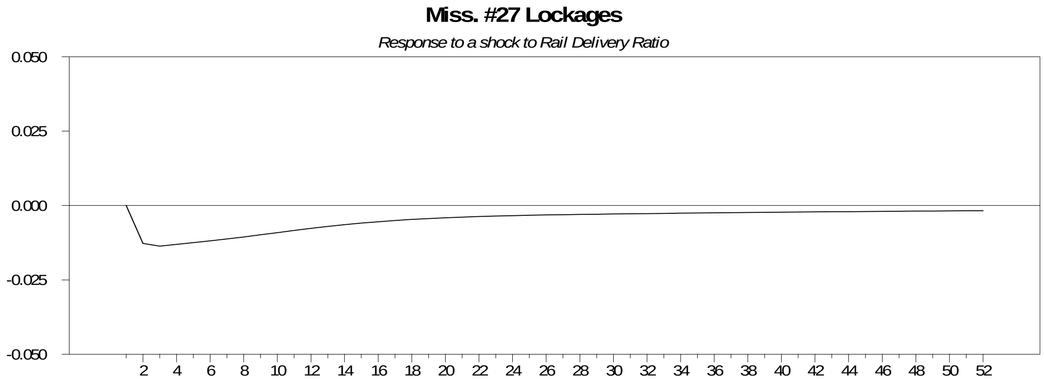


FIGURE 2a Response of Lockages to a Shock to the Rail Delivery Ratio

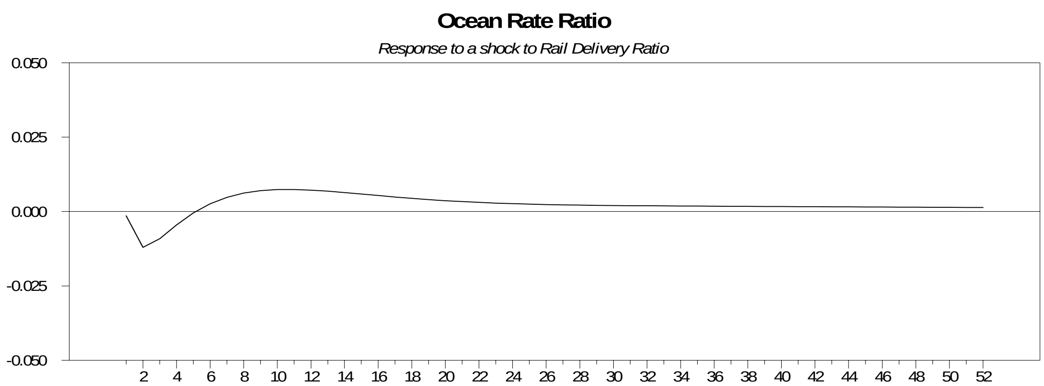


FIGURE 2b Response of Ocean Freight Rate Ratio to a Shock to the Rail Delivery Ratio

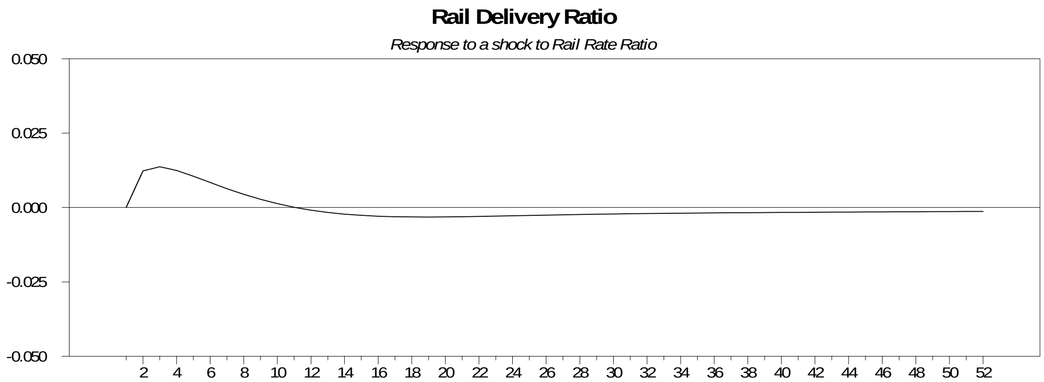


FIGURE 3a Response of the Rail Delivery Ratio to a Shock to the Rail Rate Ratio

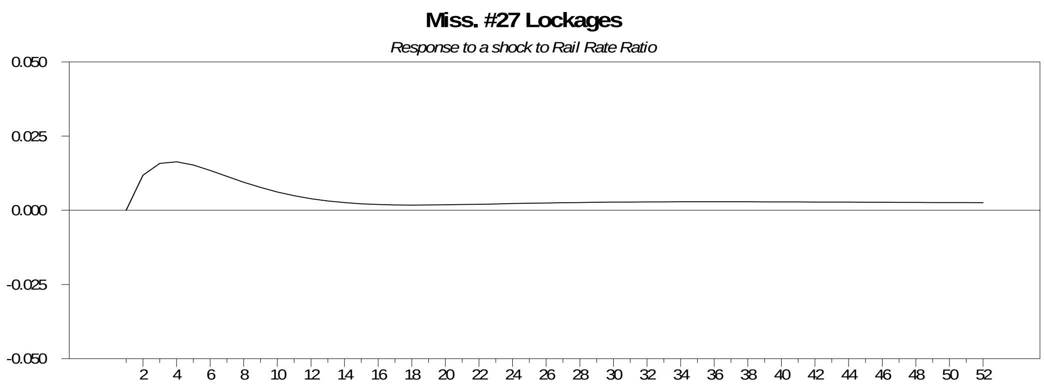


FIGURE 3b Response of Lockages to a Shock to the Rail Rate Ratio

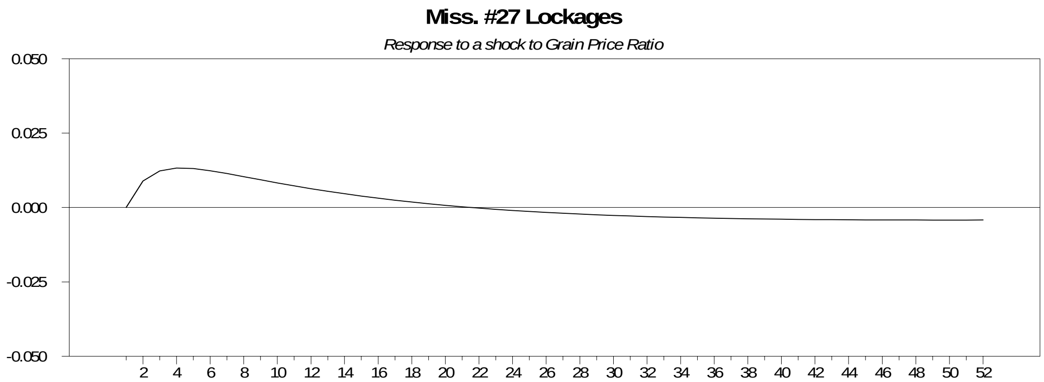


FIGURE 4a Response of Lockages to a Shock to the Grain Price Ratio

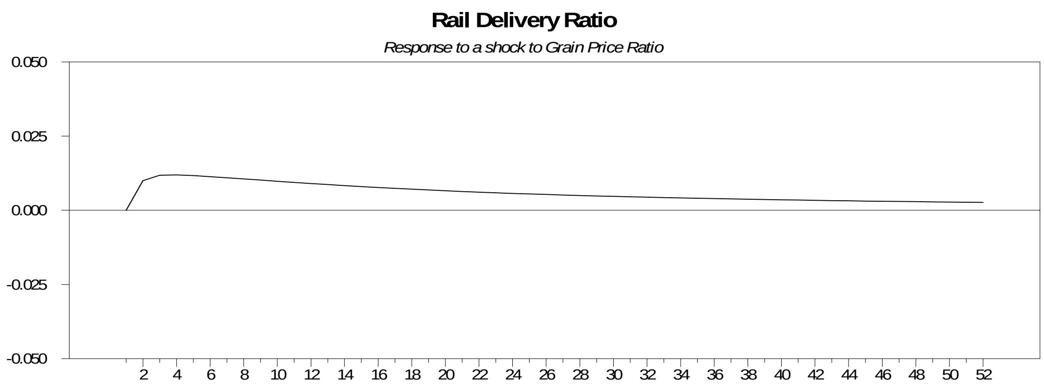


FIGURE 4b Response of the Rail Delivery Ratio to a Shock to the Grain Price Ratio

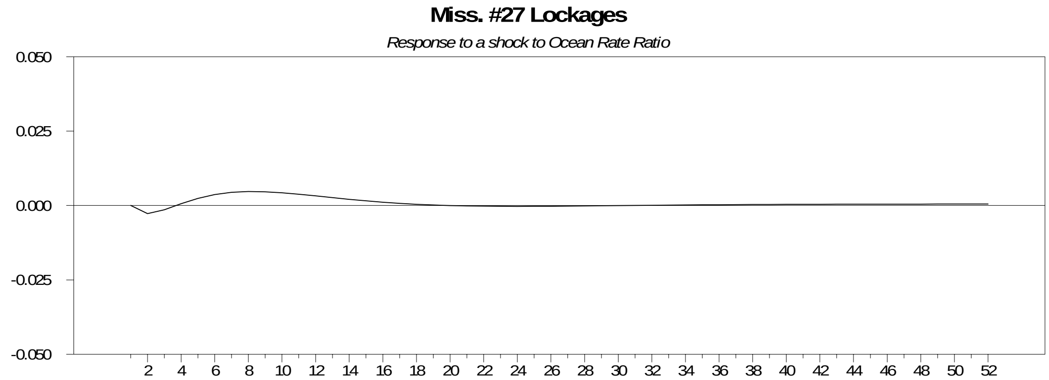


FIGURE 5a Response of Lockages to a Shock to the Ocean Freight Ratio

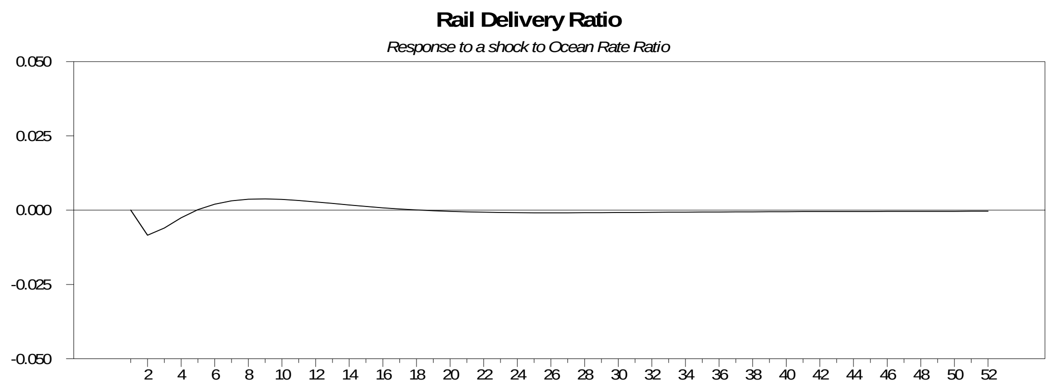


FIGURE 5b Response of the Rail Delivery Ratio to a Shock to the Ocean Freight Ratio

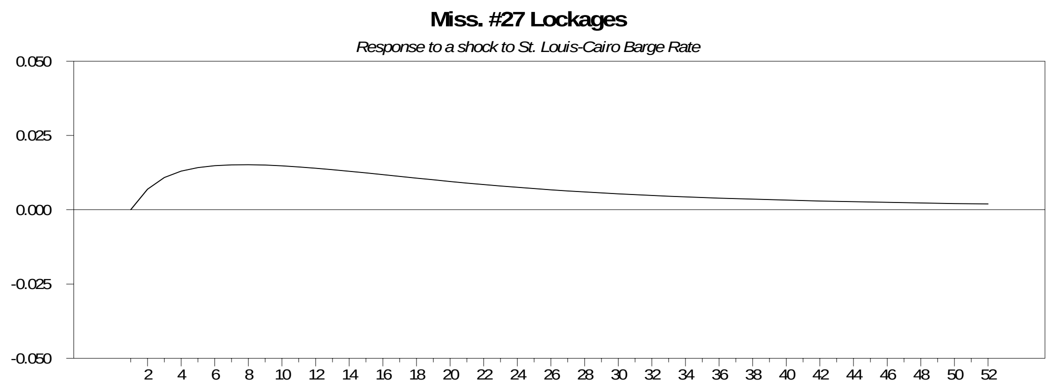


FIGURE 6a Response of Lockages to a Shock to the Barge Rate

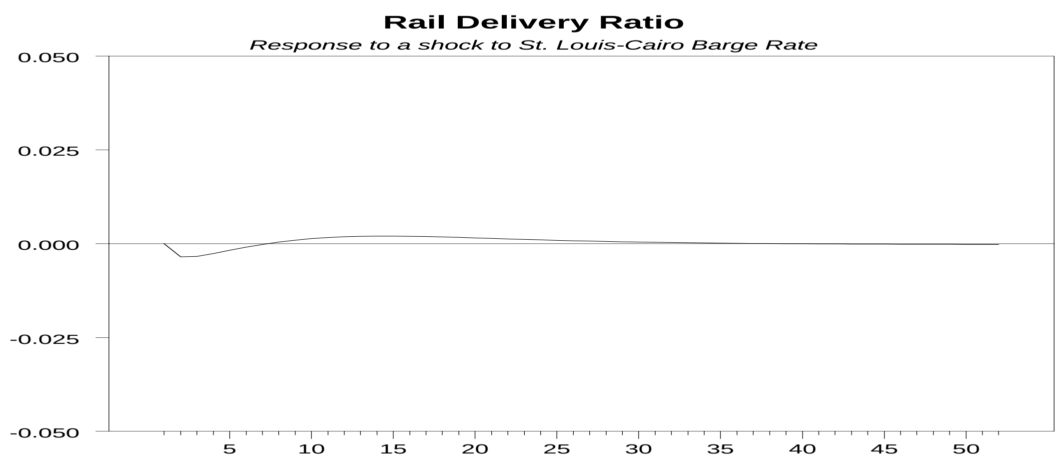
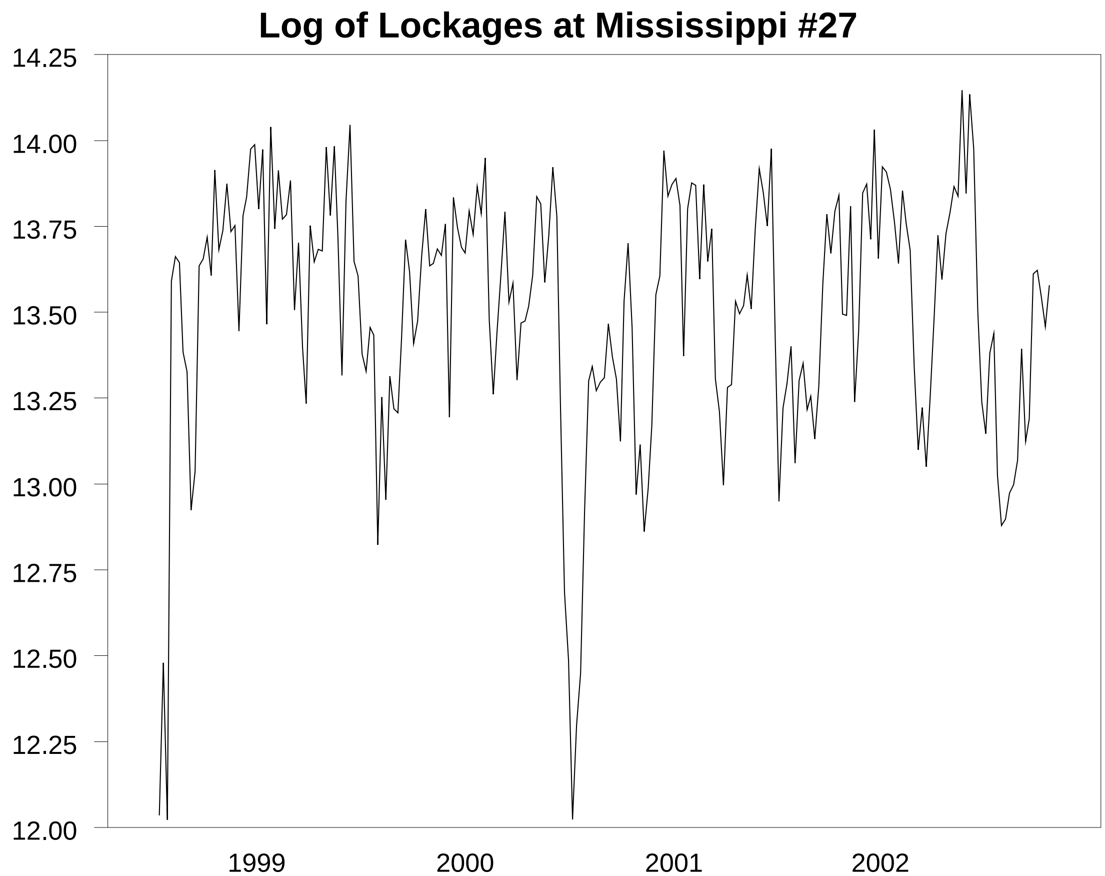
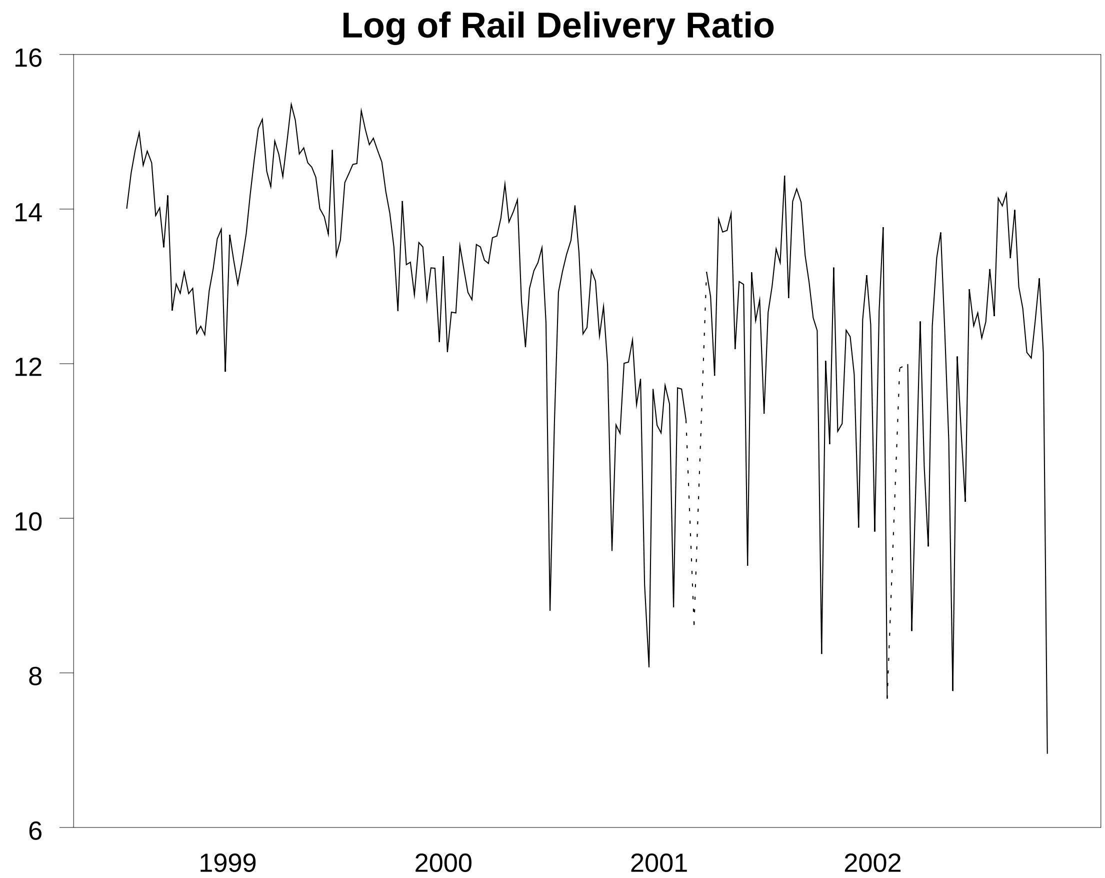


FIGURE 6b Response of Rail Deliveries to a Shock to the Barge Rate

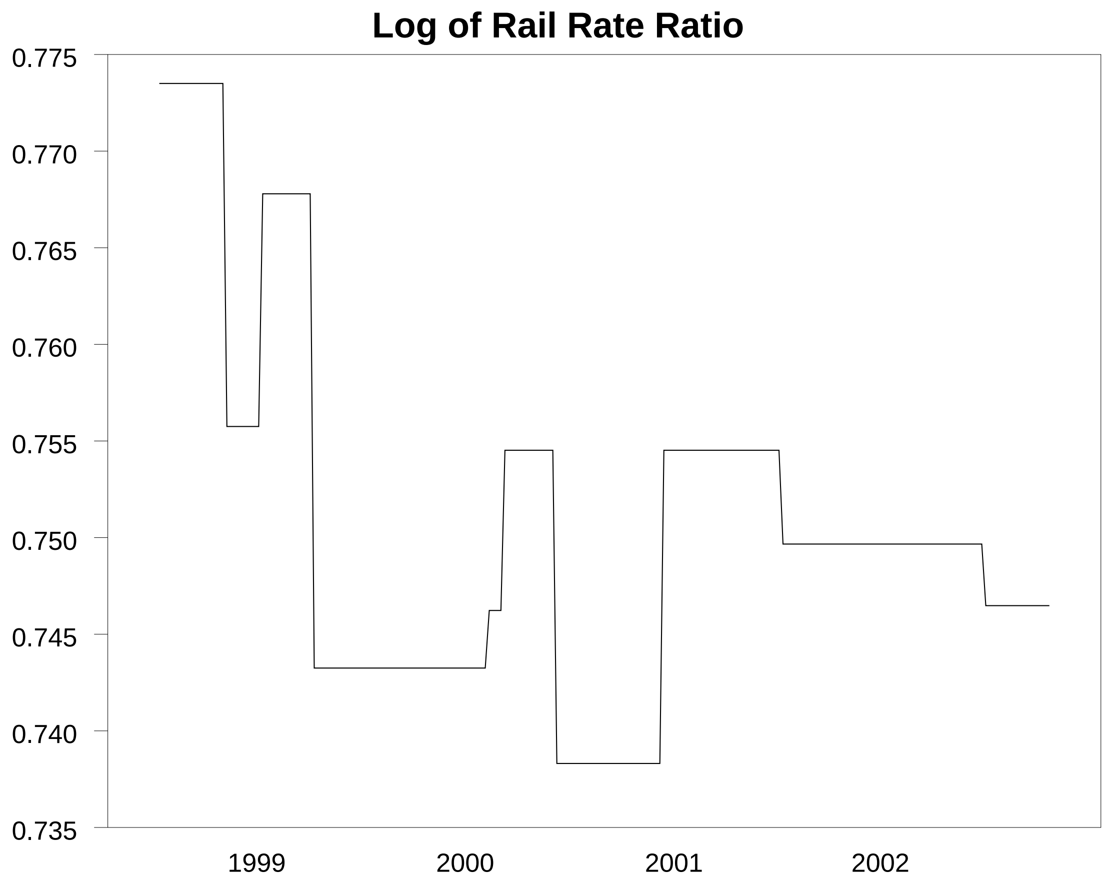
Appendix A

Graphs of Data used in Estimation

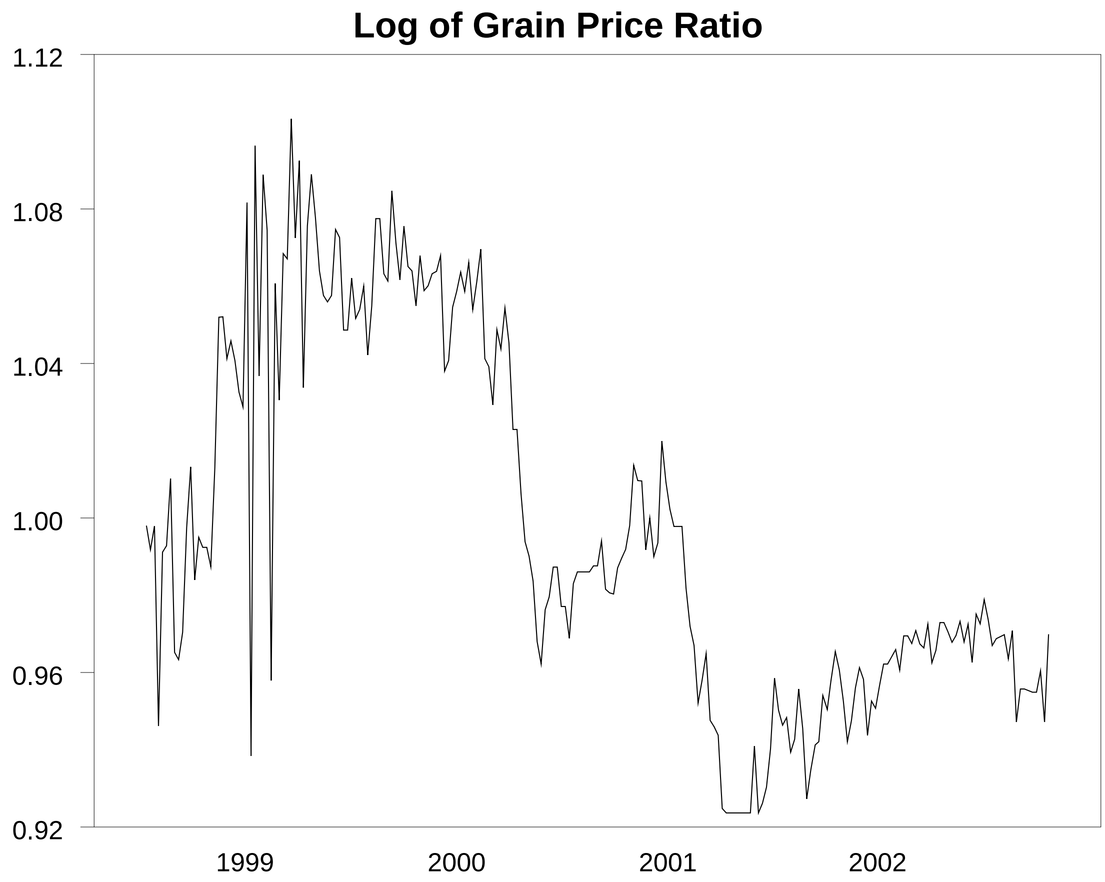

Log of Lockages at Mississippi #27
14.25
14.00
13.75
13.50
13.25
13.00
12.75
12.50
12.25
12.00
1999
2000
2001
2002

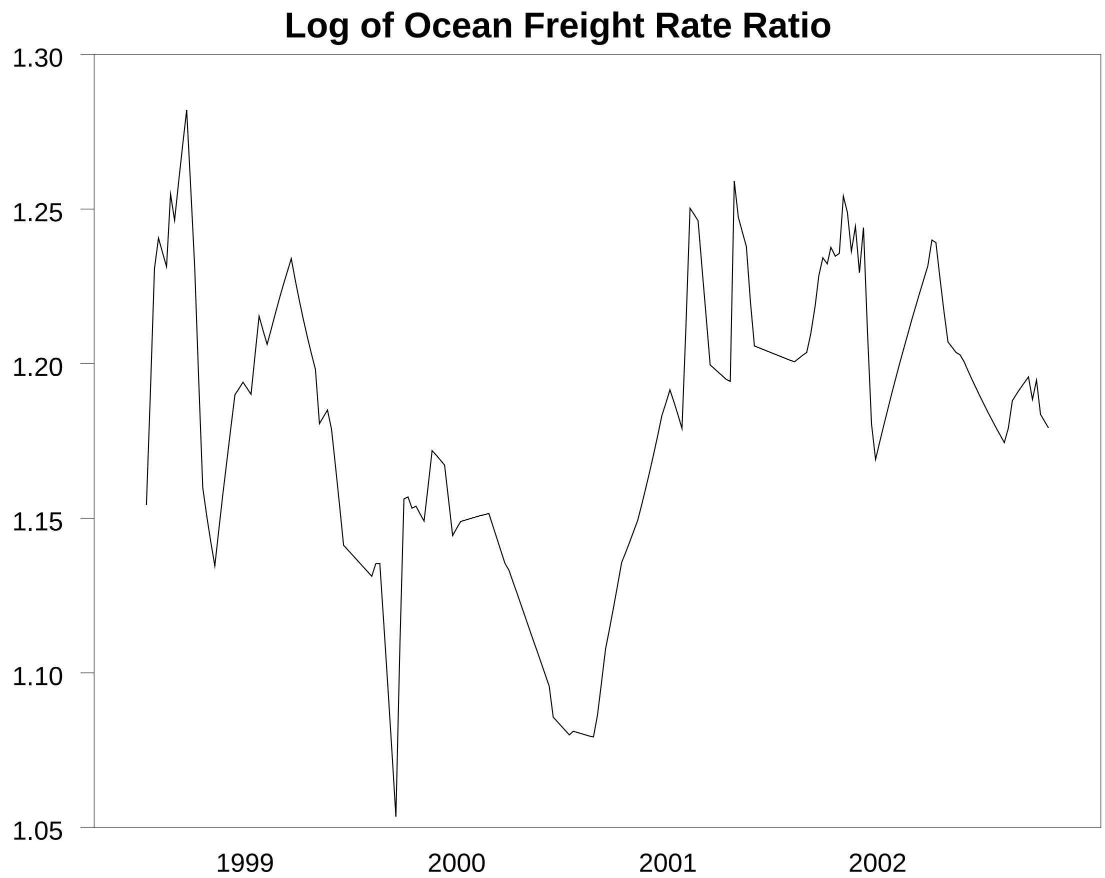


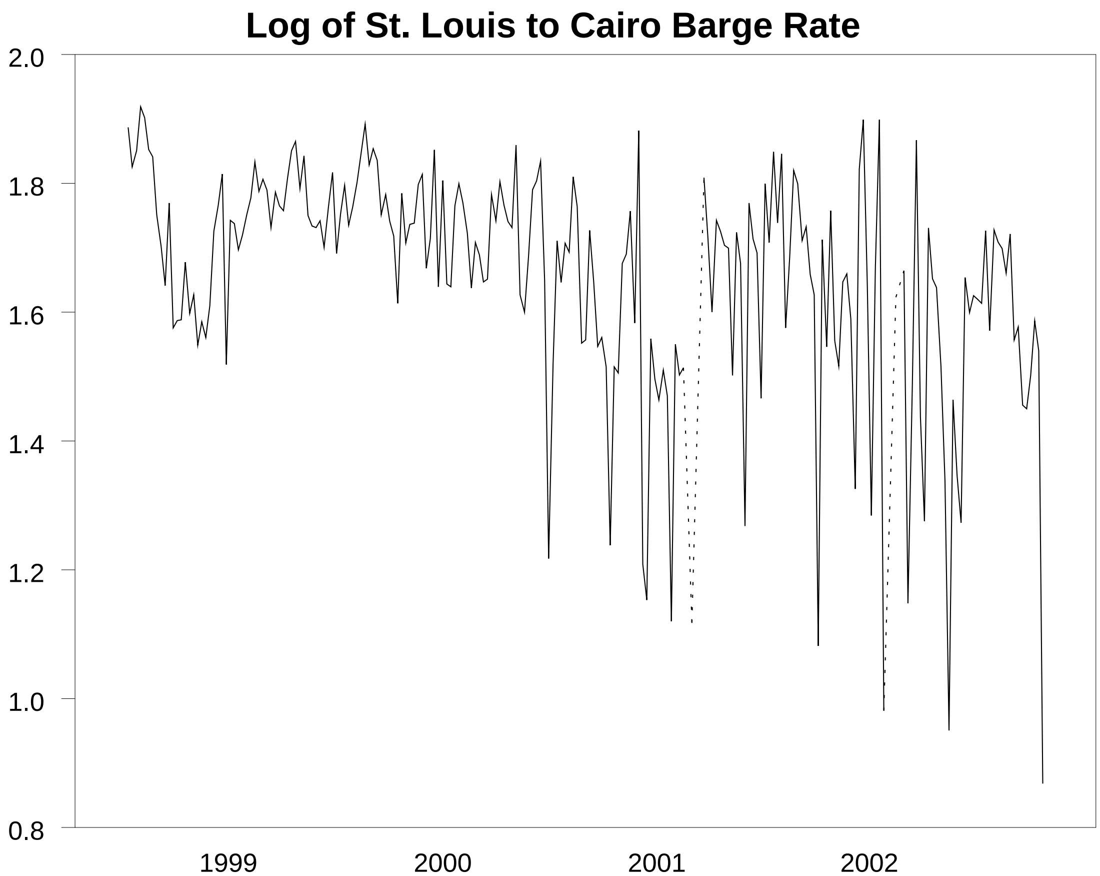
Log of Rail Delivery Ratio
16
14
12
10
8
6
1999
2000
2001
2002



Log of Rail Rate Ratio
0.775
0.770
0.765
0.760
0.755
0.750
0.745
0.740
0.735
1999
2000
2001
2002


Log of Grain Price Ratio
1.12
1.08
1.04
1.00
0.96
0.92
1999
2000
2001
2002


Log of Ocean Freight Rate Ratio
1.30
1.25
1.20
1.15
1.10
1.05
1999
2000
2001
2002

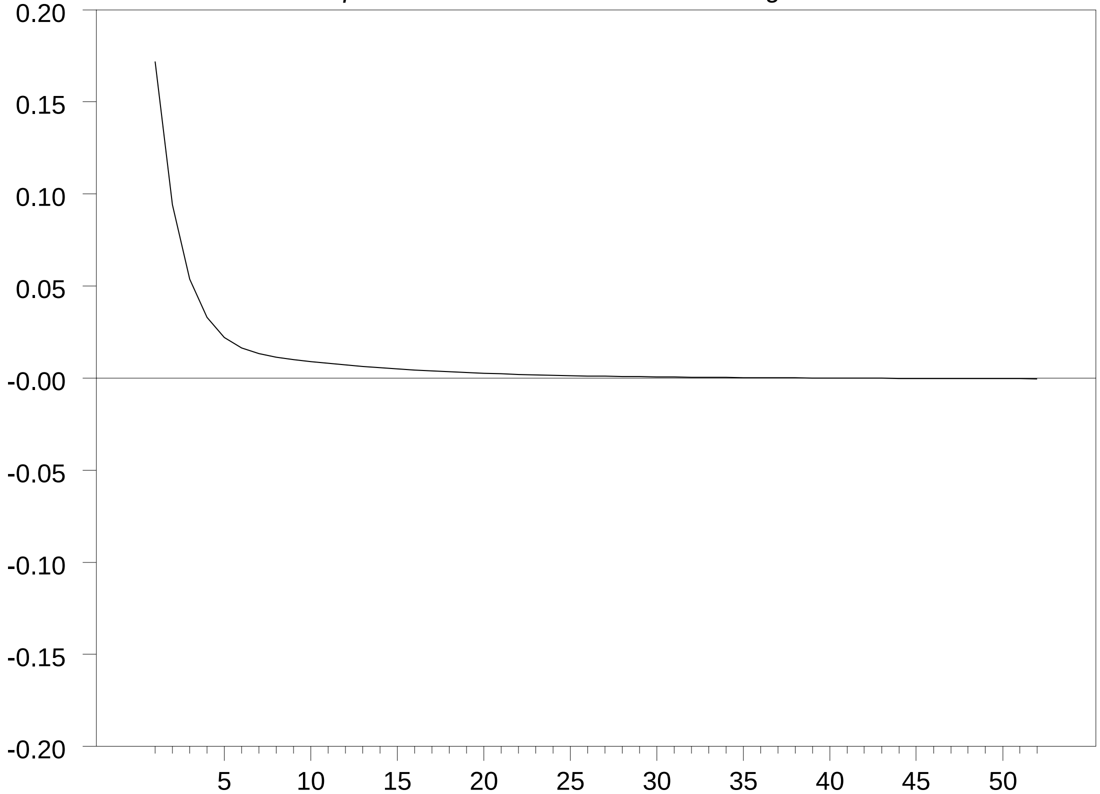

Log of St. Louis to Cairo Barge Rate
2.0
1.8
1.6
1.4
1.2
1.0
0.8
1999
2000
2001
2002

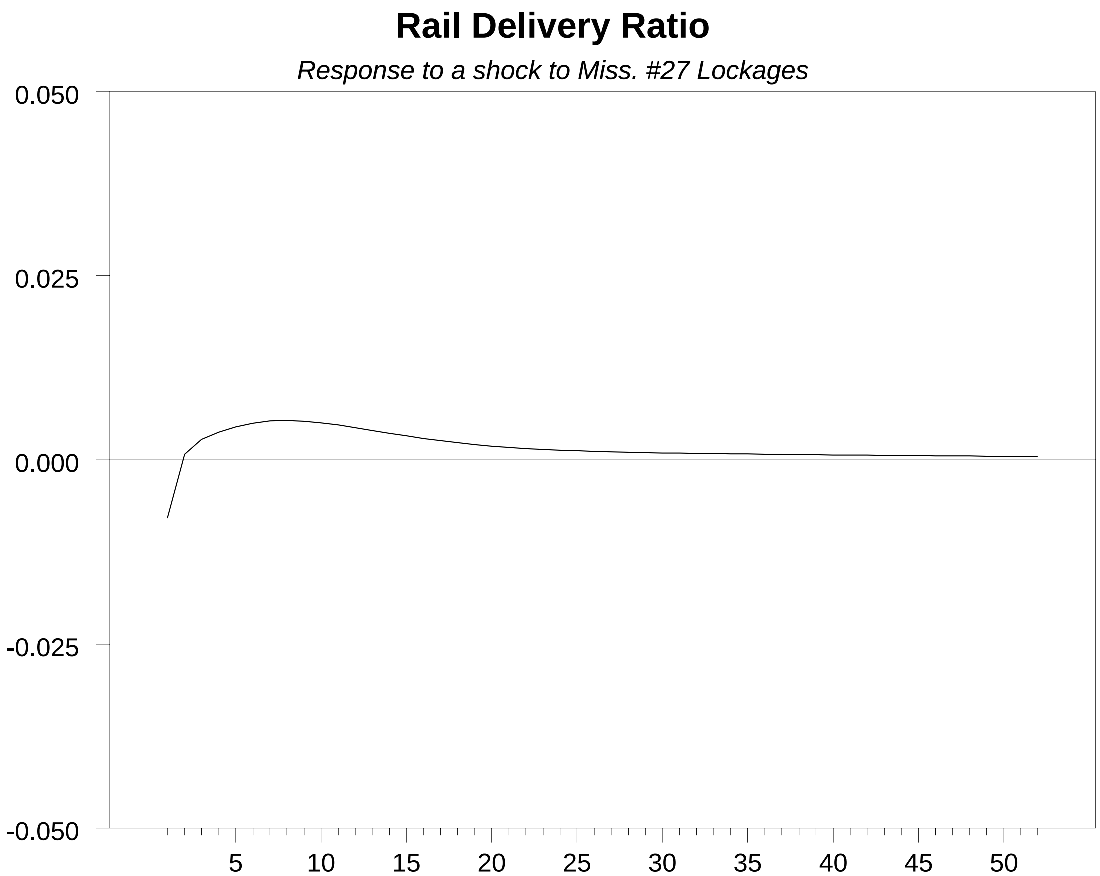
Appendix B

Complete Set of Impulse Response Functions

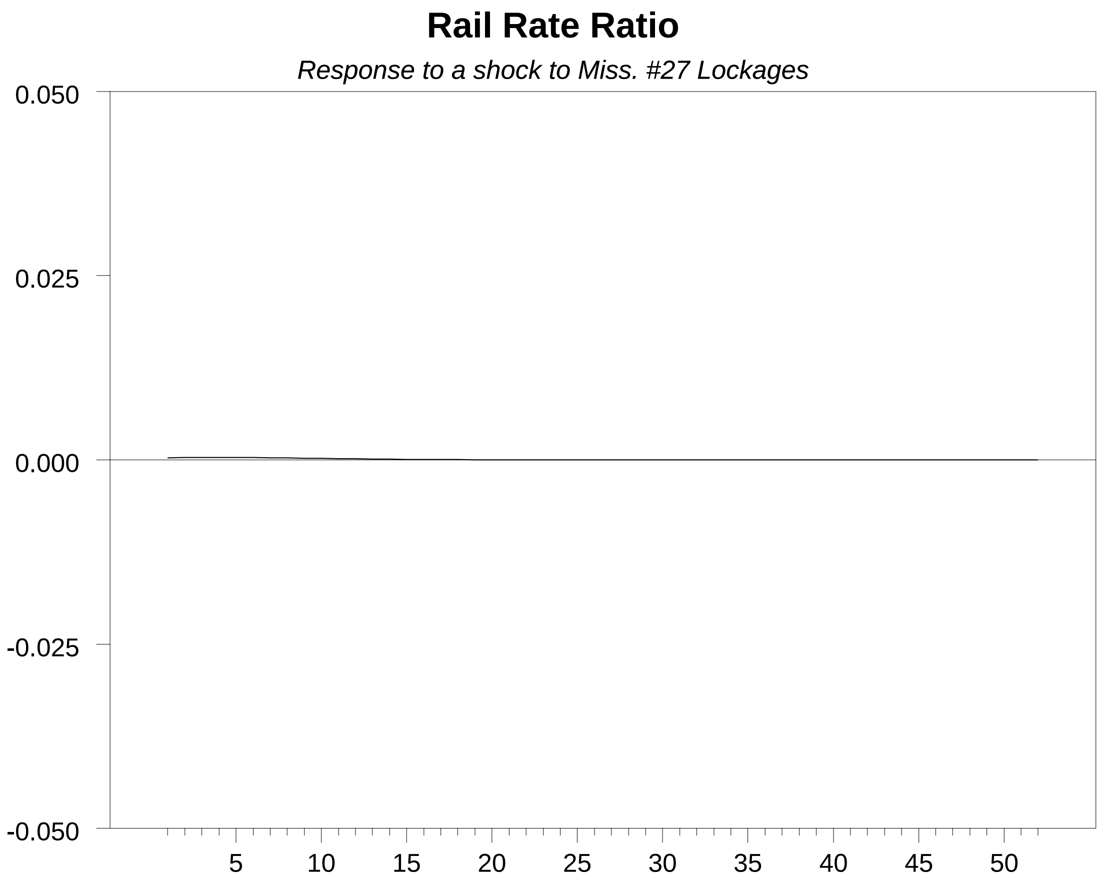
Miss. #27 Lockages

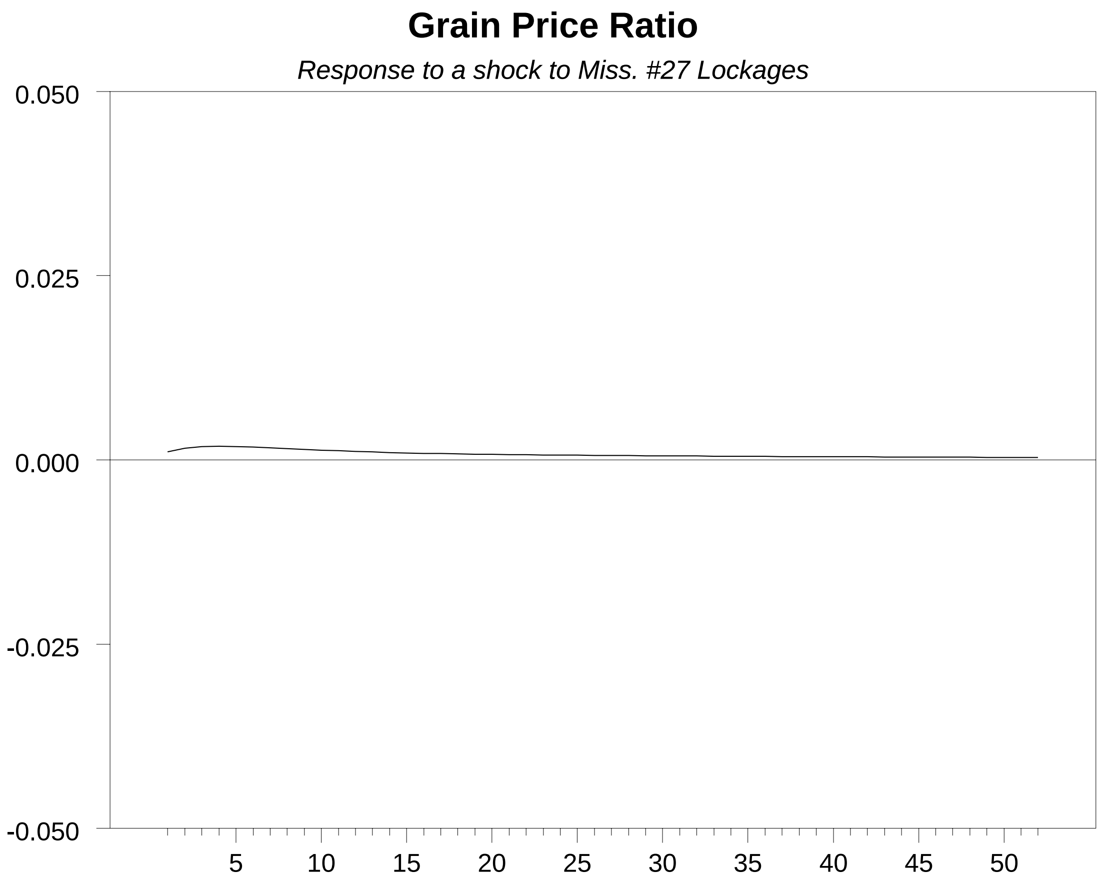
Response to a shock to Miss. #27 Lockages

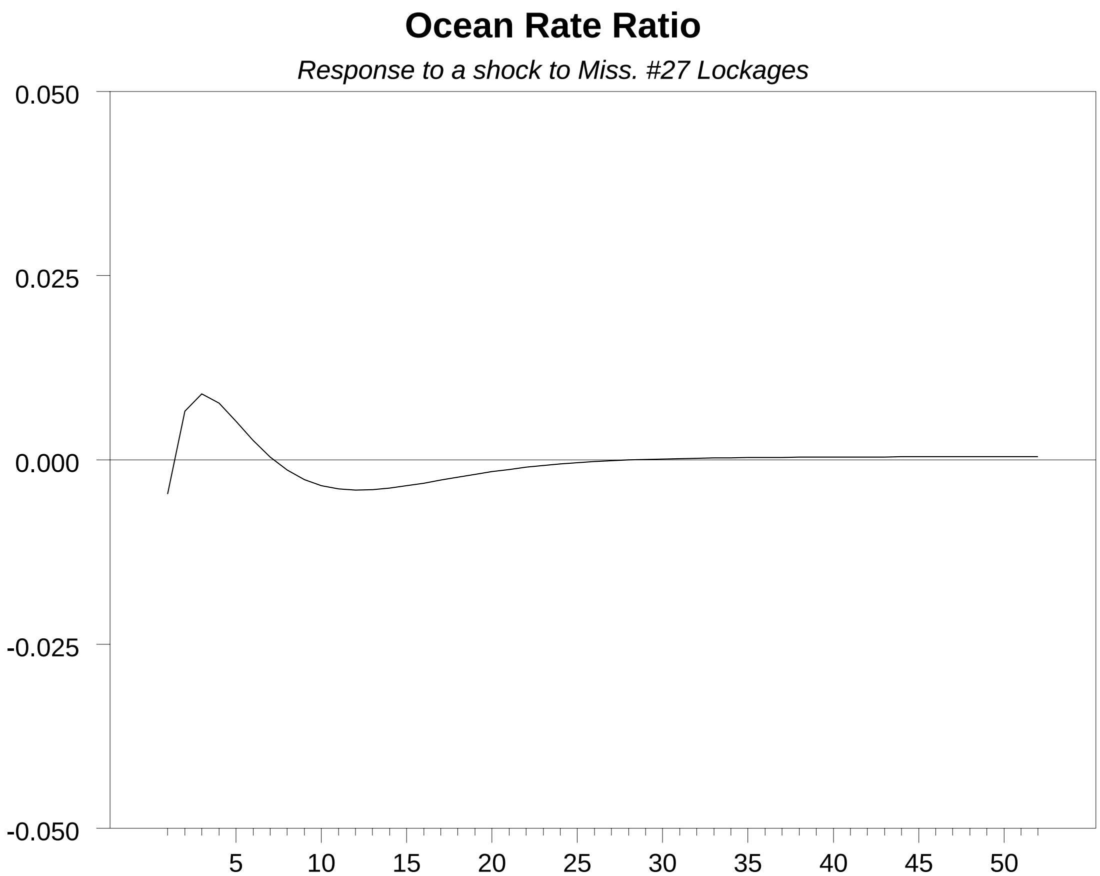


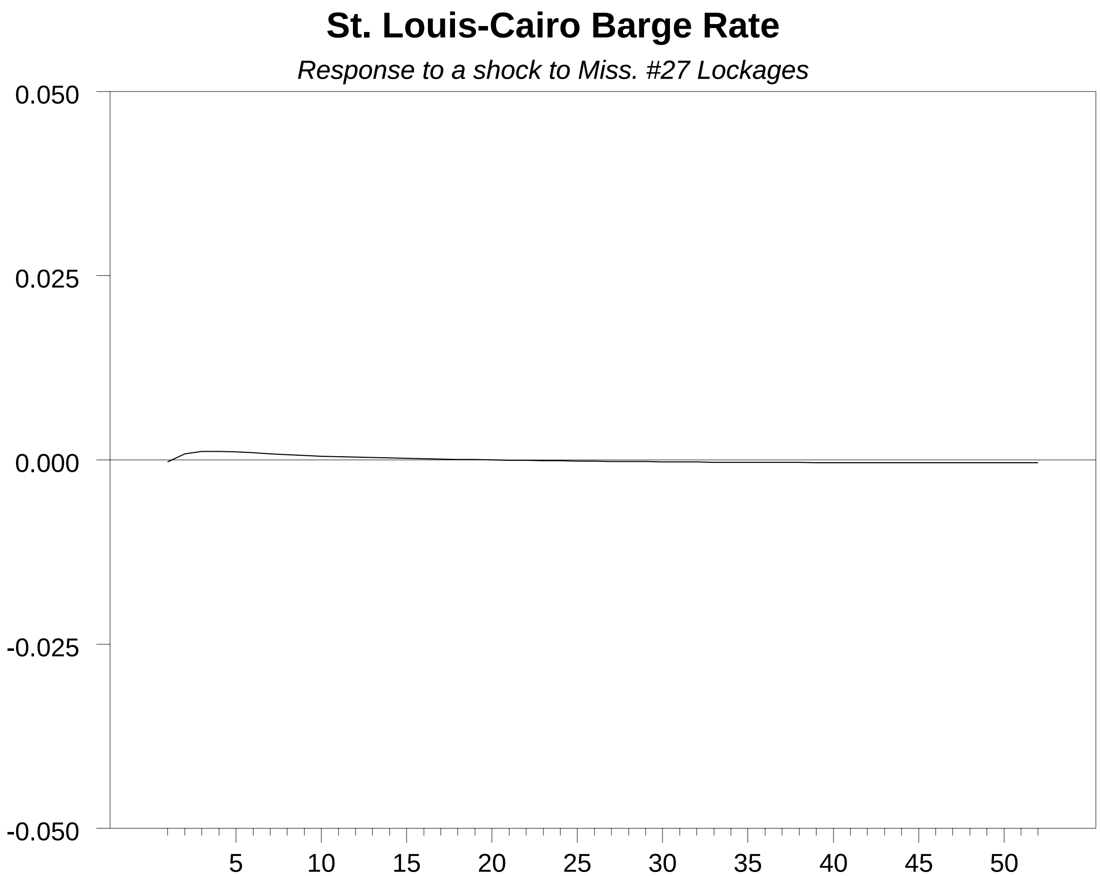


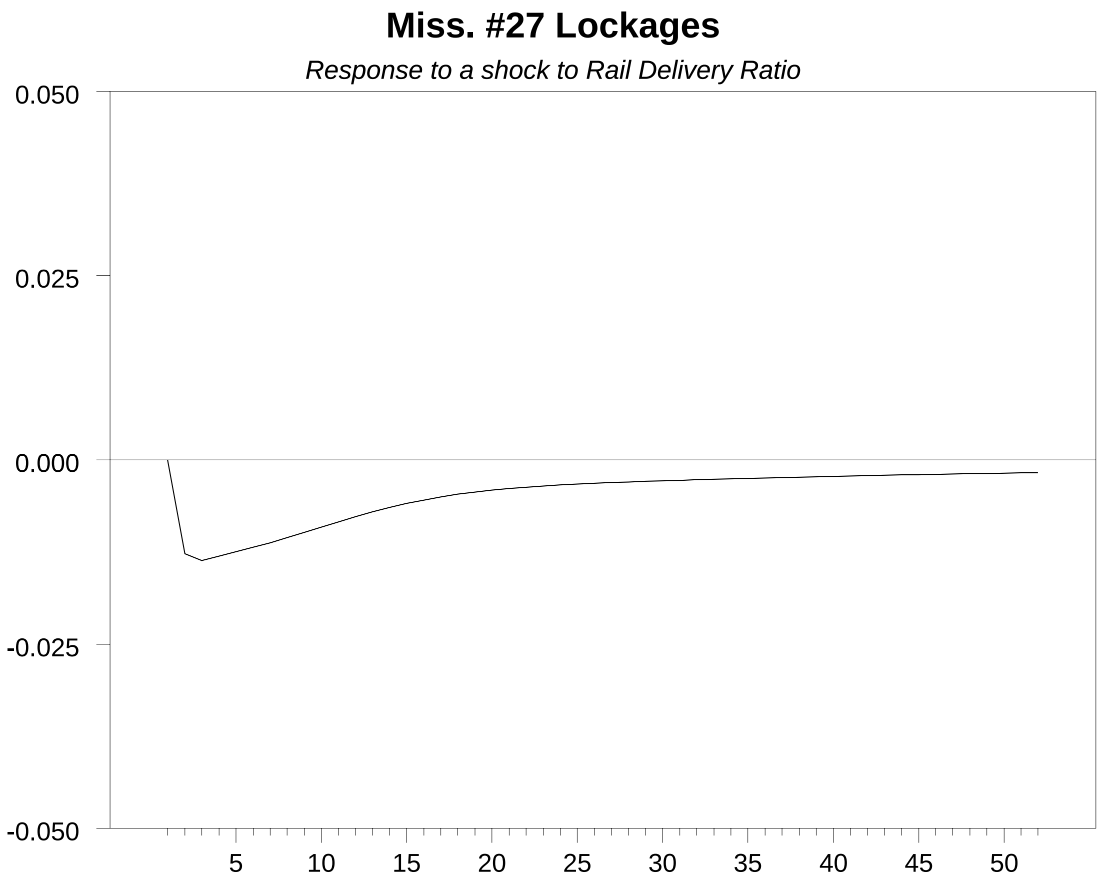
Rail Delivery Ratio
Response to a shock to Miss. #27 Lockages
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

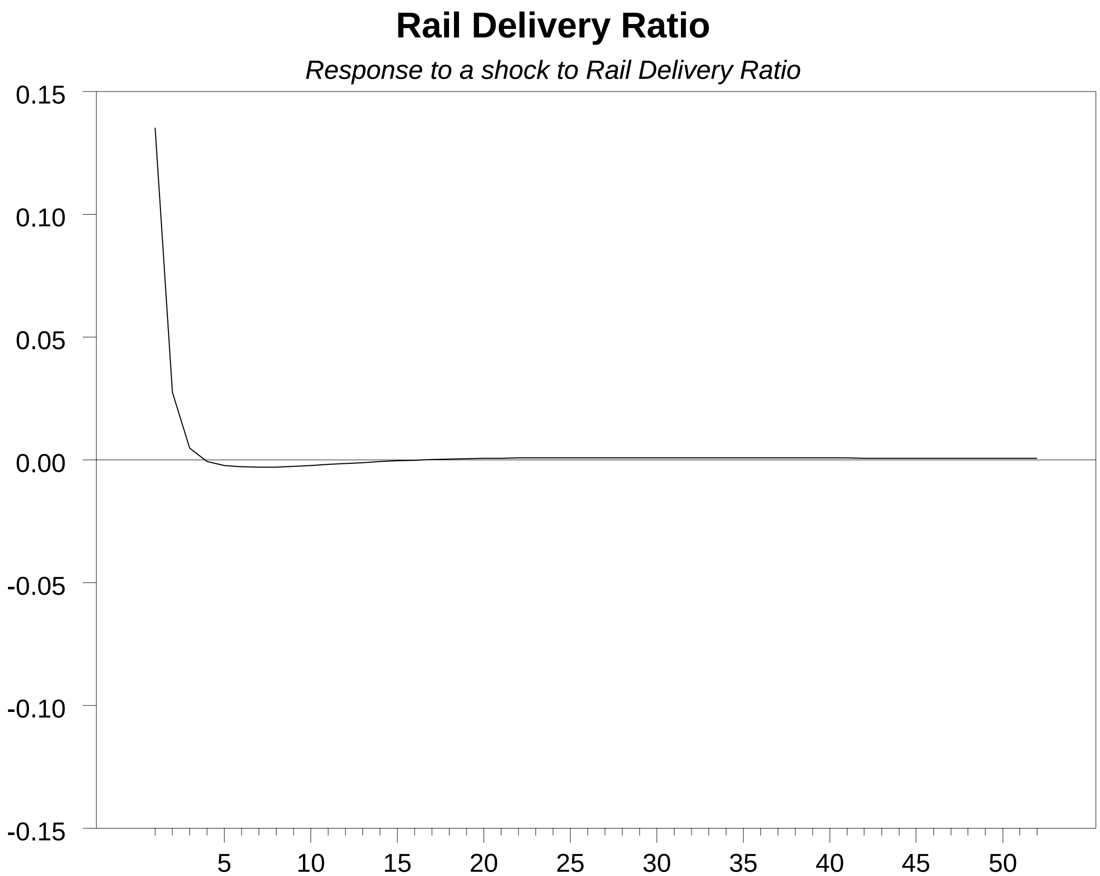

Rail Rate Ratio
Response to a shock to Miss. #27 Lockages
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50


Grain Price Ratio
Response to a shock to Miss. #27 Lockages
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

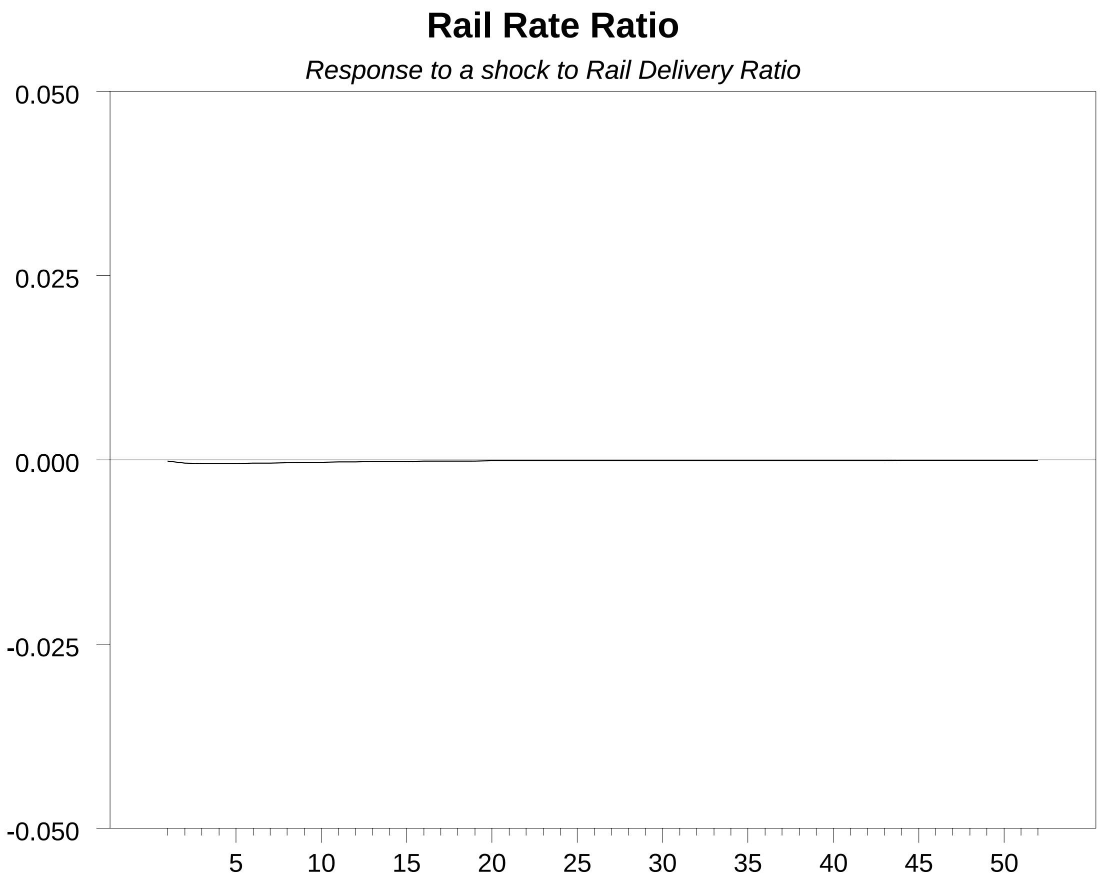

Ocean Rate Ratio
Response to a shock to Miss. #27 Lockages
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

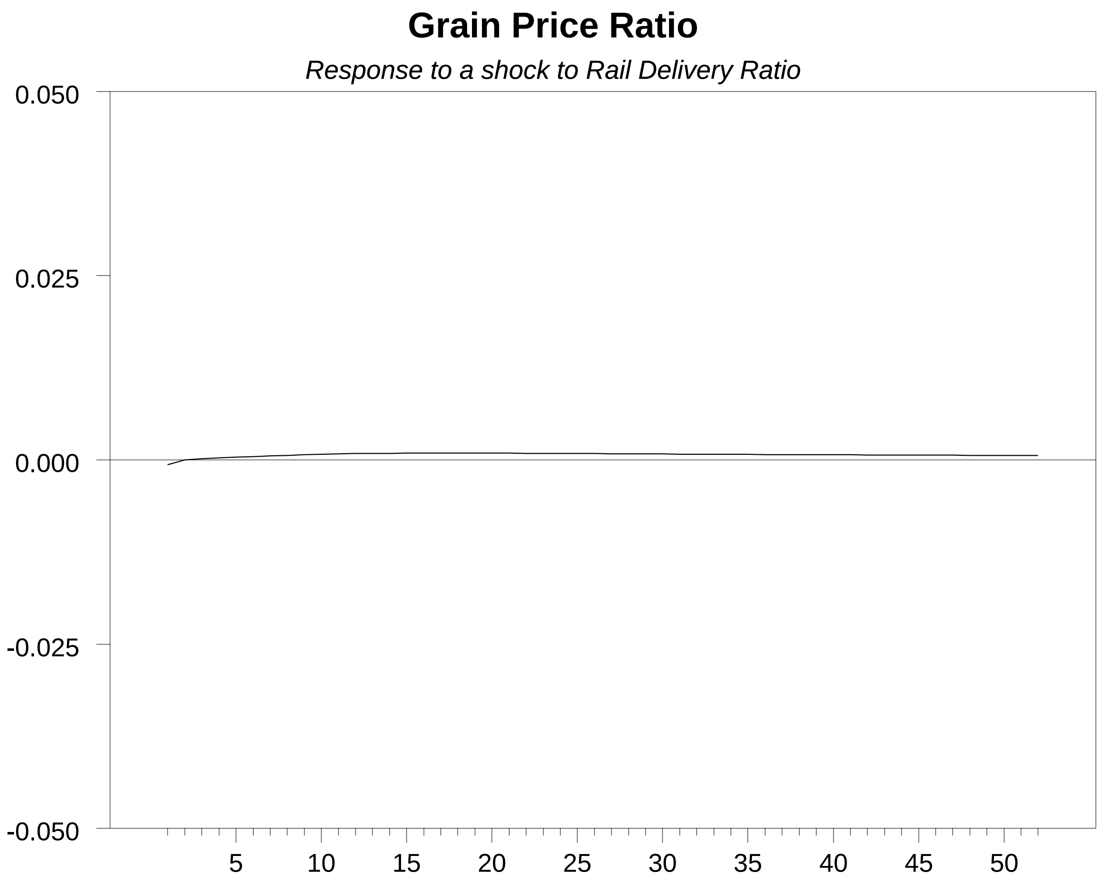

St. Louis-Cairo Barge Rate
Response to a shock to Miss. #27 Lockages
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

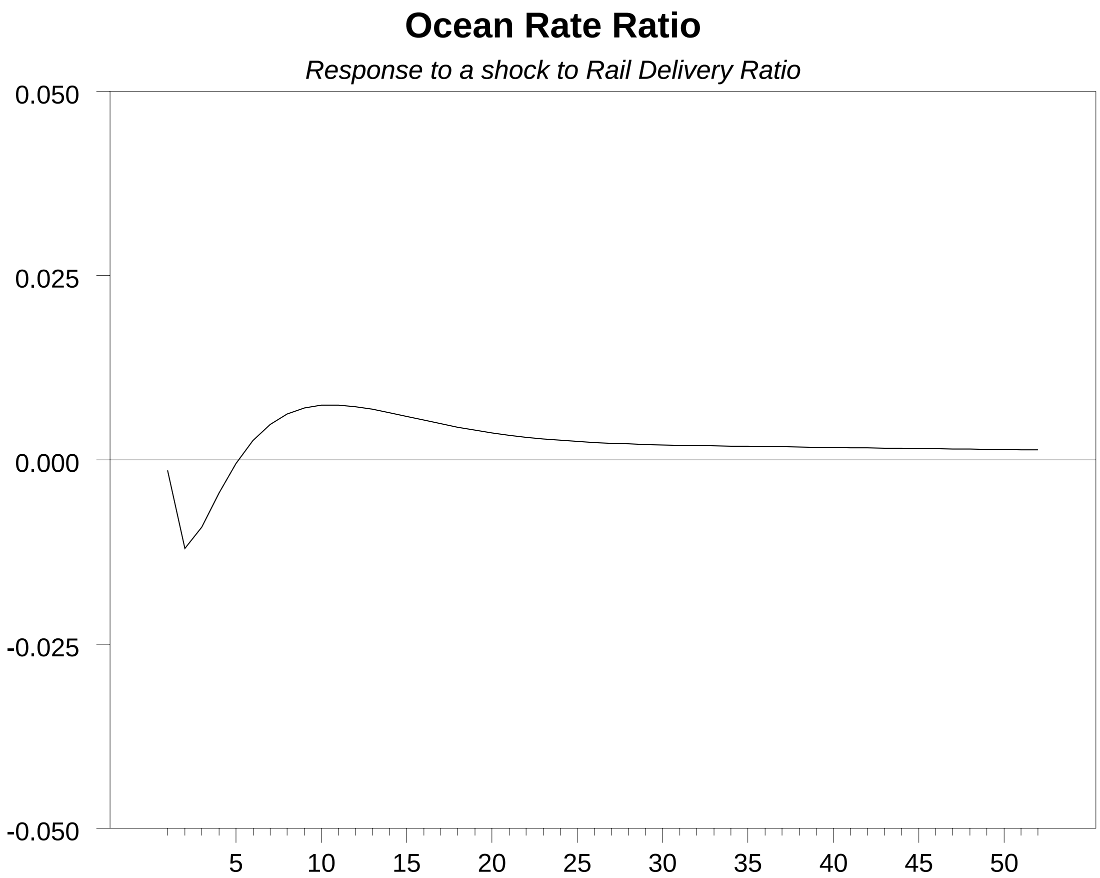

Miss. #27 Lockages
Response to a shock to Rail Delivery Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50



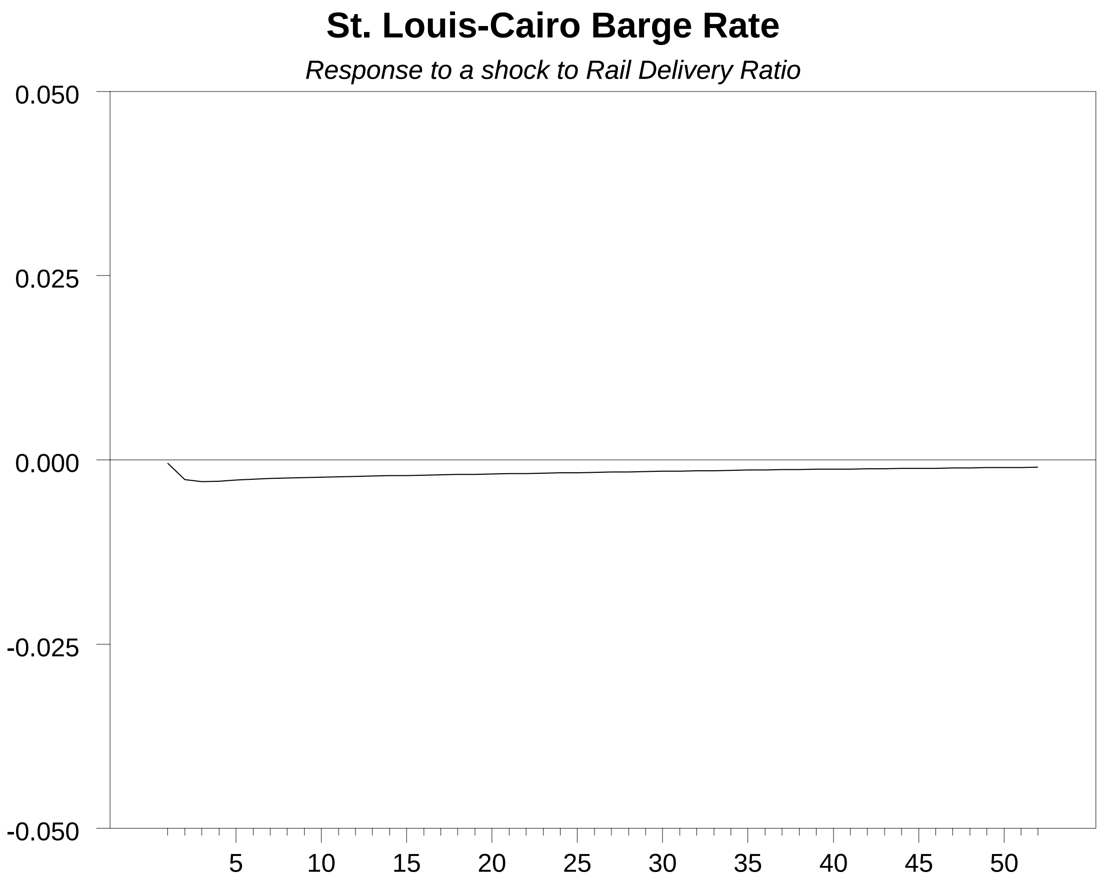
Rail Delivery Ratio
Response to a shock to Rail Delivery Ratio
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
5
10
15
20
25
30
35
40
45
50

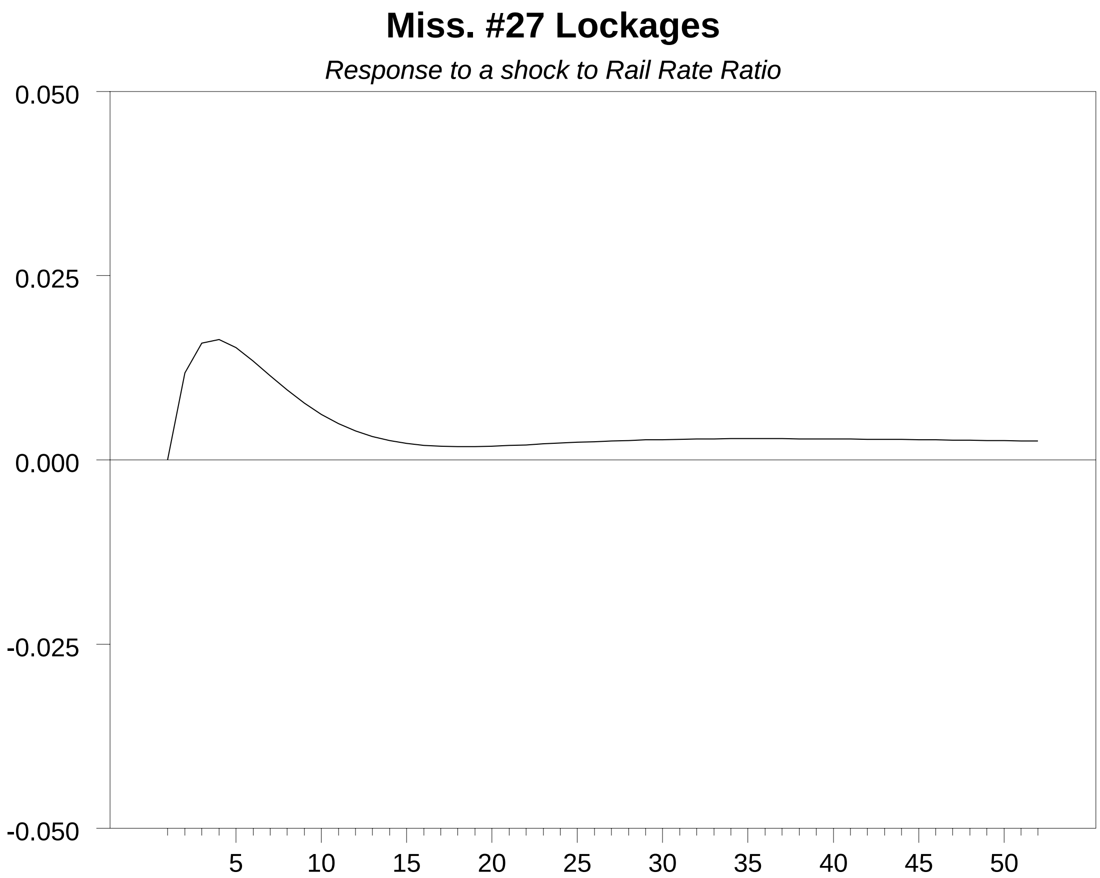

Rail Rate Ratio
Response to a shock to Rail Delivery Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

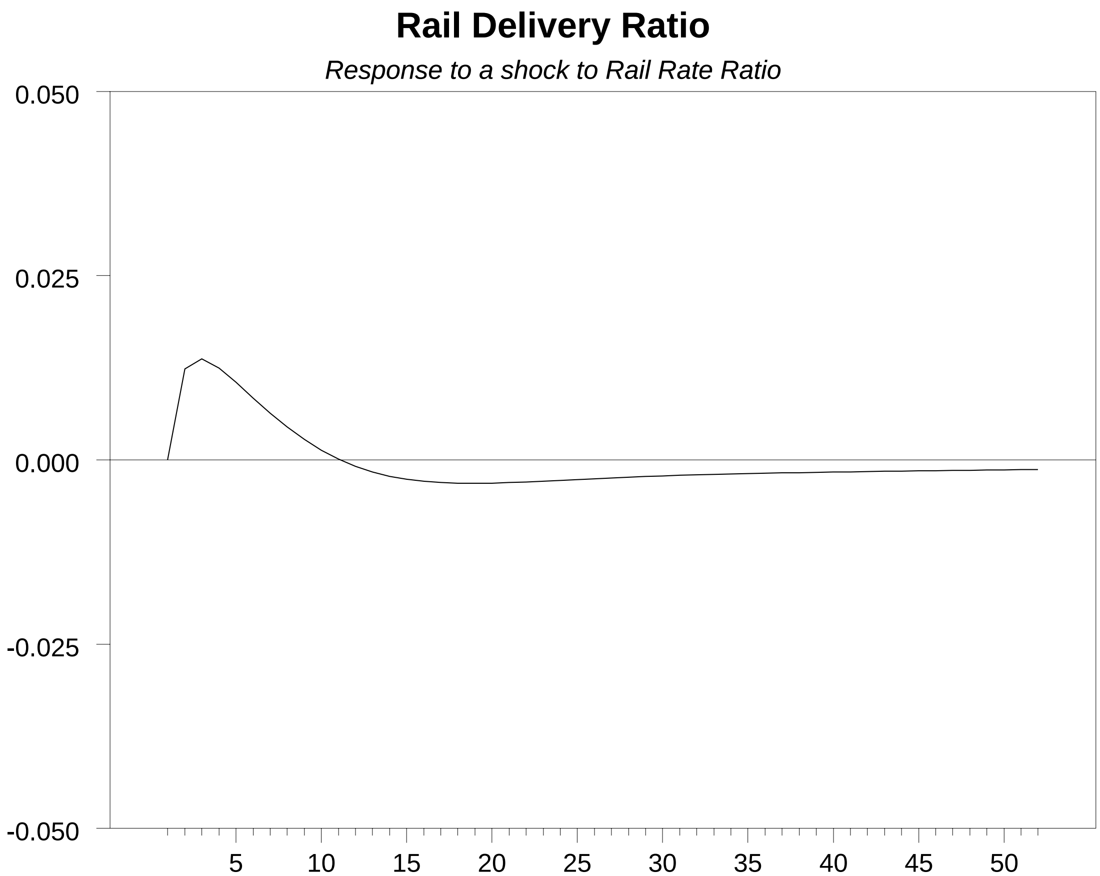

Grain Price Ratio
Response to a shock to Rail Delivery Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50



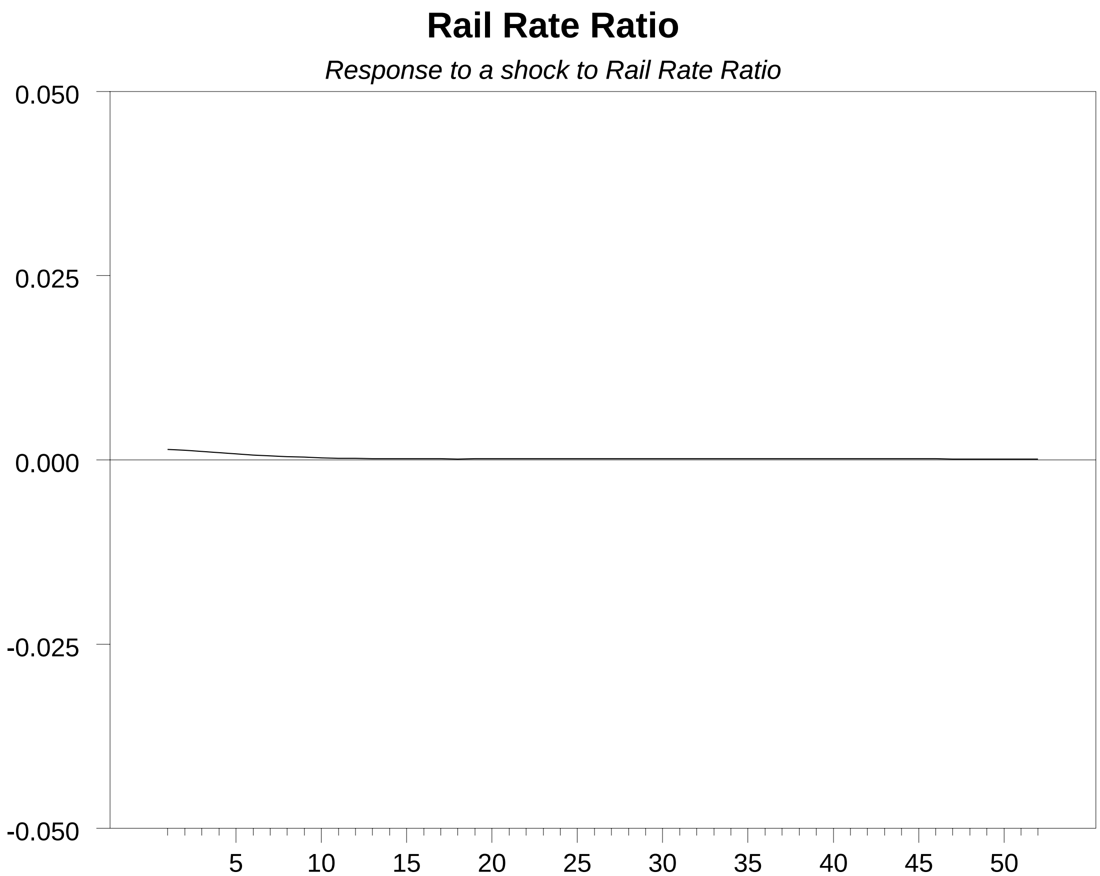
Ocean Rate Ratio
Response to a shock to Rail Delivery Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

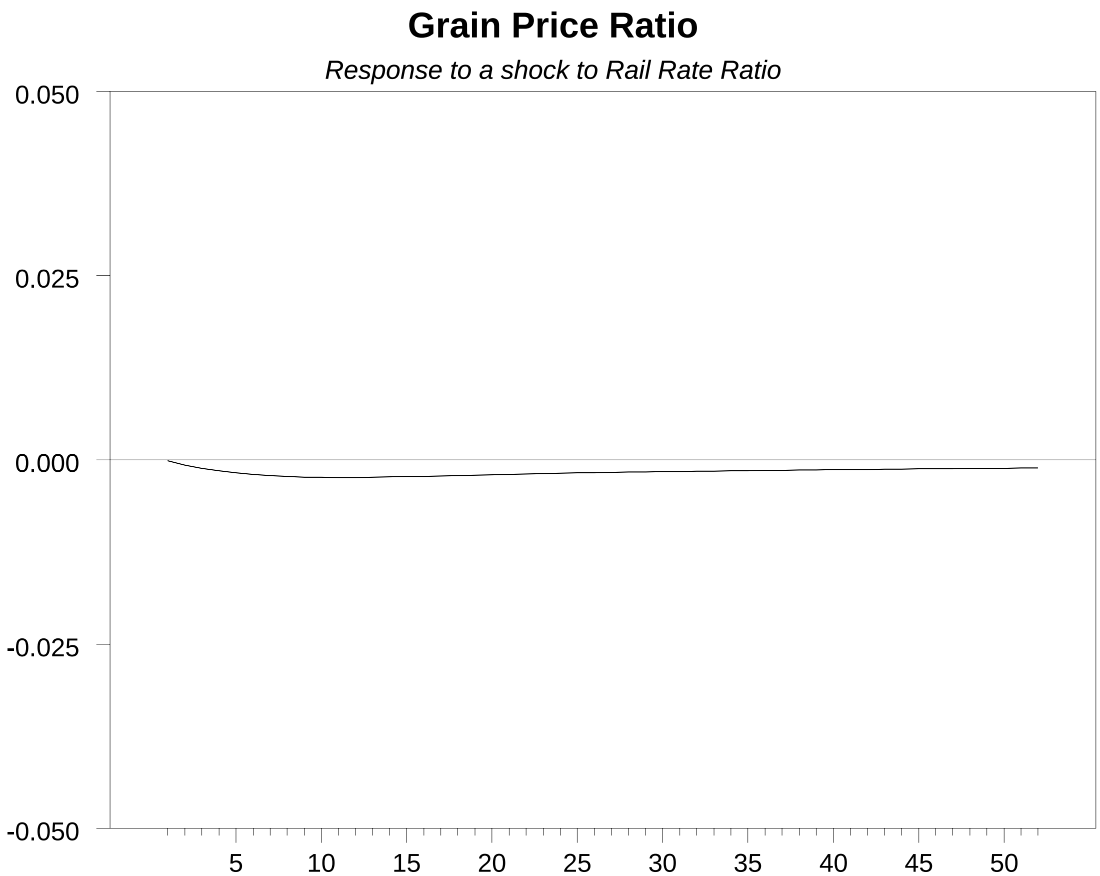

St. Louis-Cairo Barge Rate
Response to a shock to Rail Delivery Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50


Miss. #27 Lockages
Response to a shock to Rail Rate Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

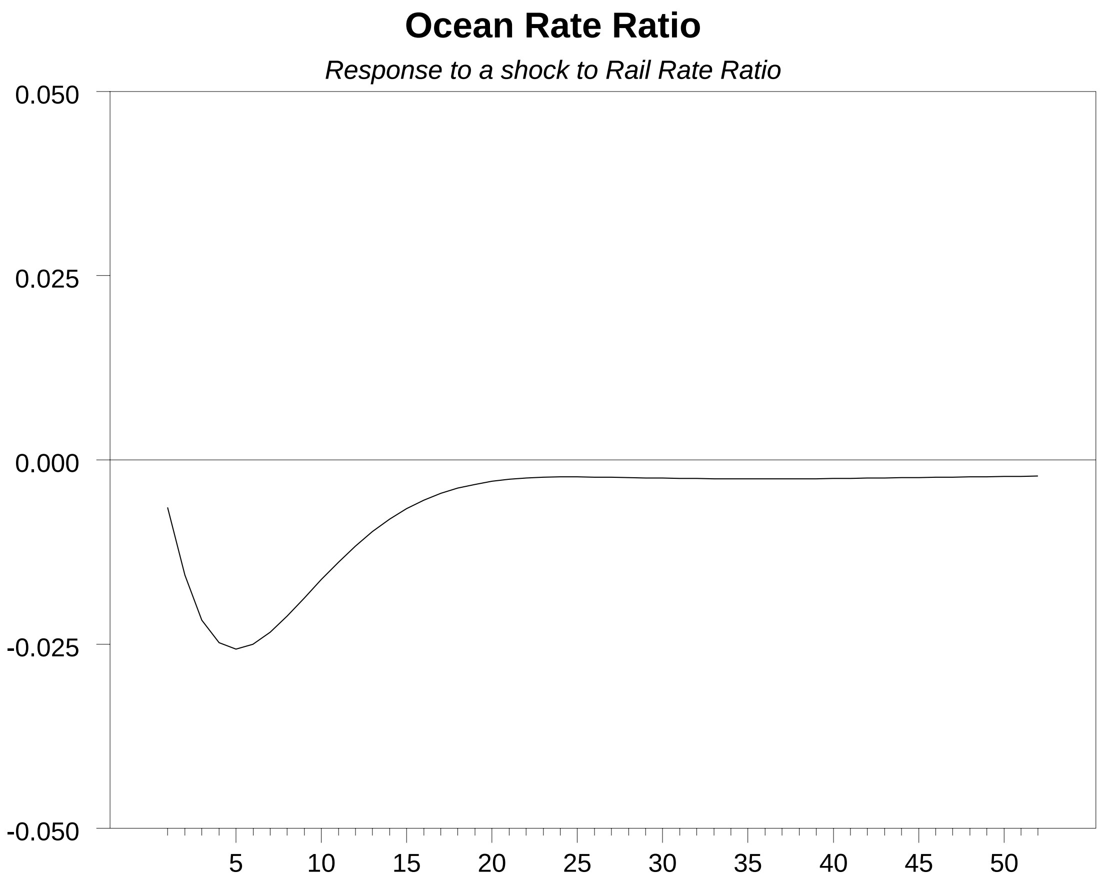


Rail Delivery Ratio
Response to a shock to Rail Rate Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

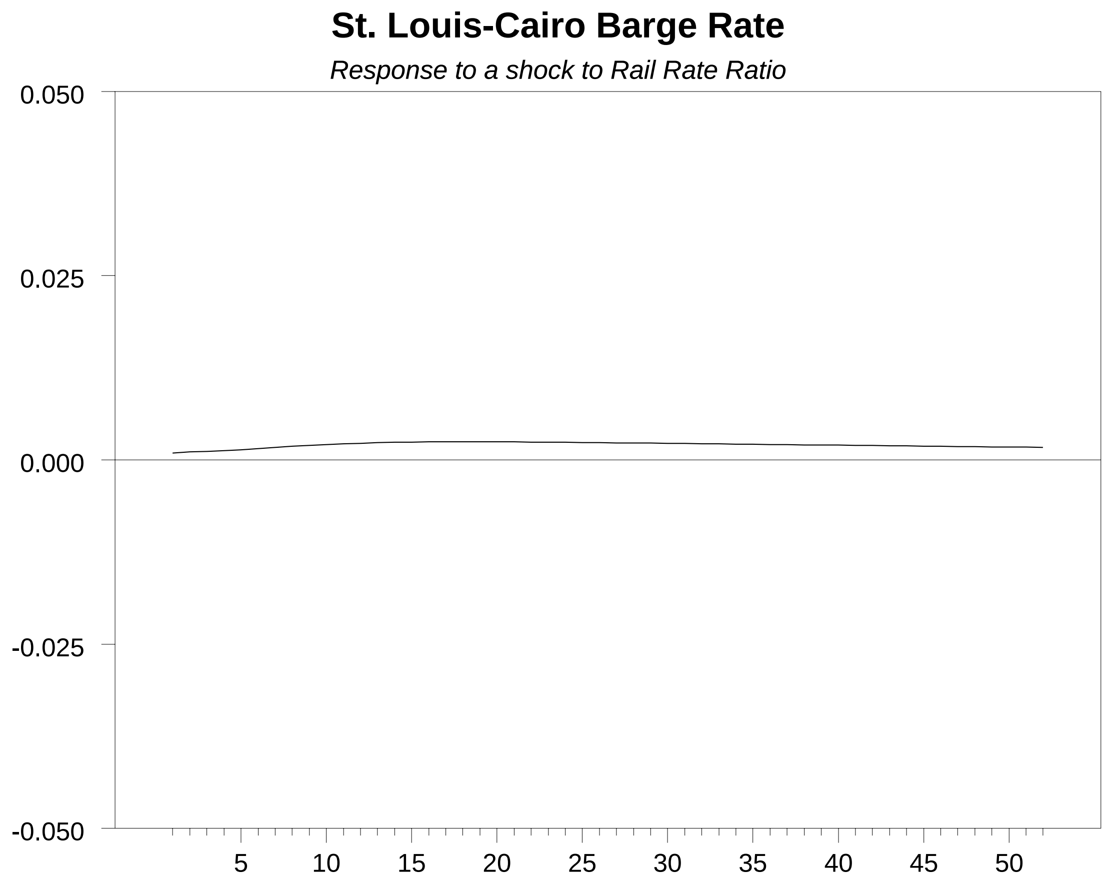

Rail Rate Ratio
Response to a shock to Rail Rate Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

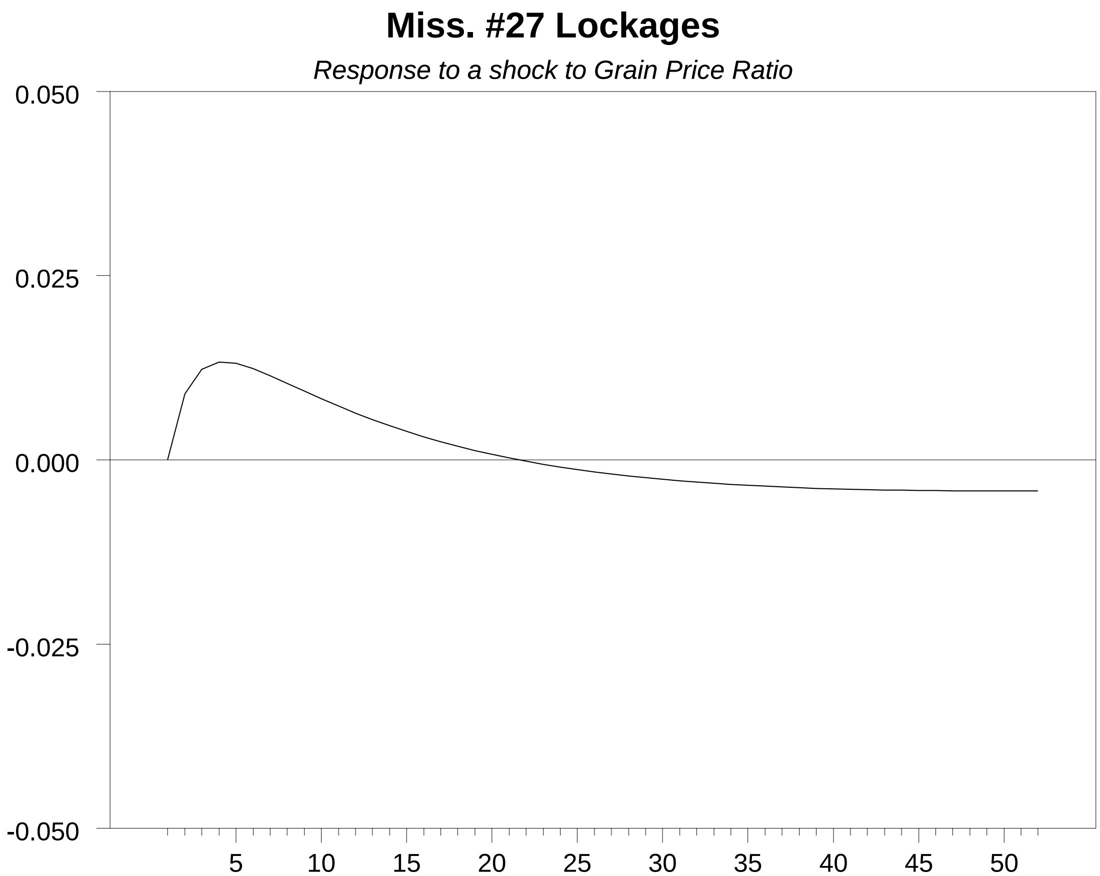


Grain Price Ratio
Response to a shock to Rail Rate Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

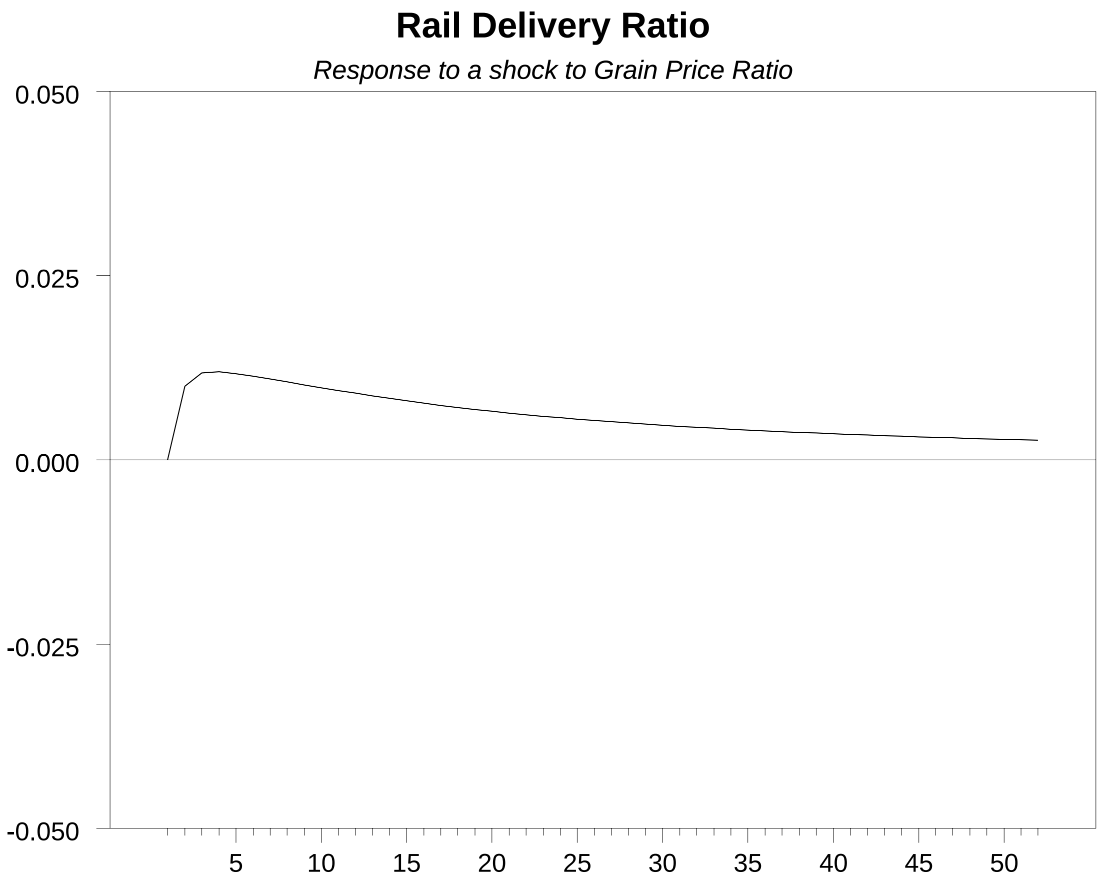


Ocean Rate Ratio
Response to a shock to Rail Rate Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

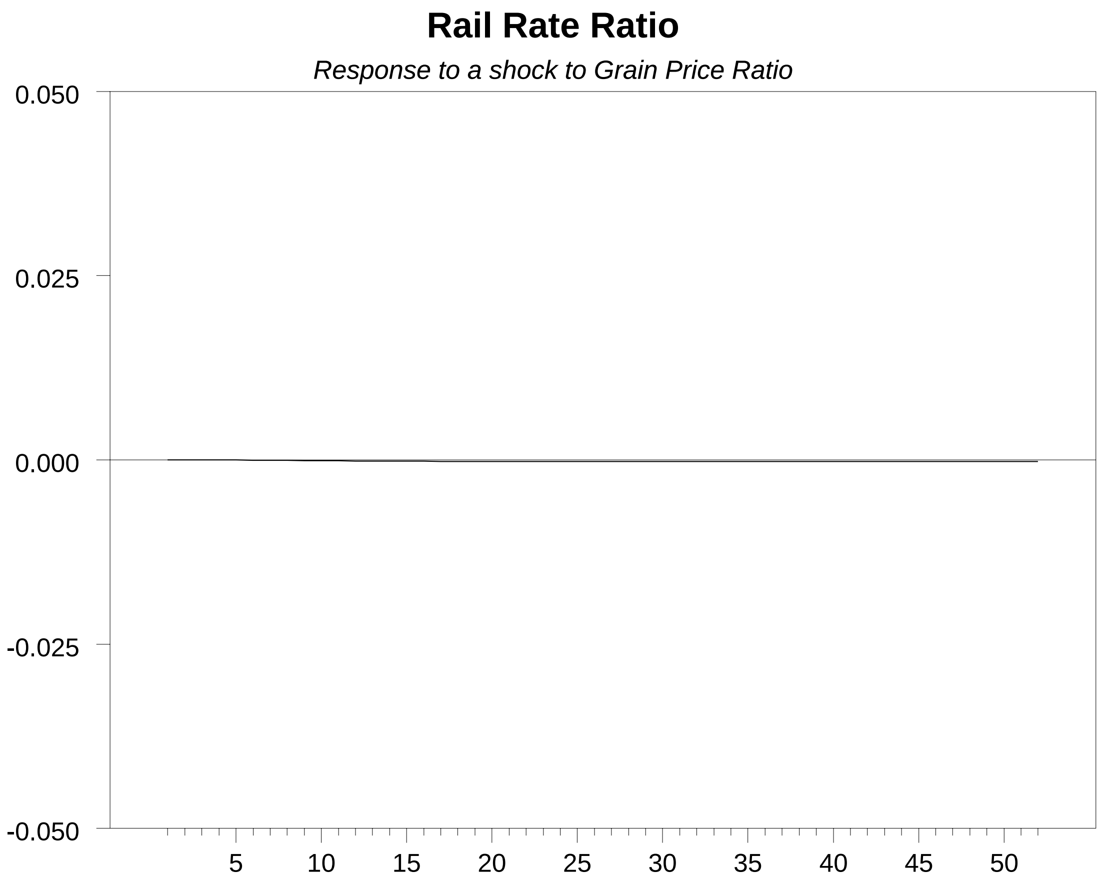

St. Louis-Cairo Barge Rate
Response to a shock to Rail Rate Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

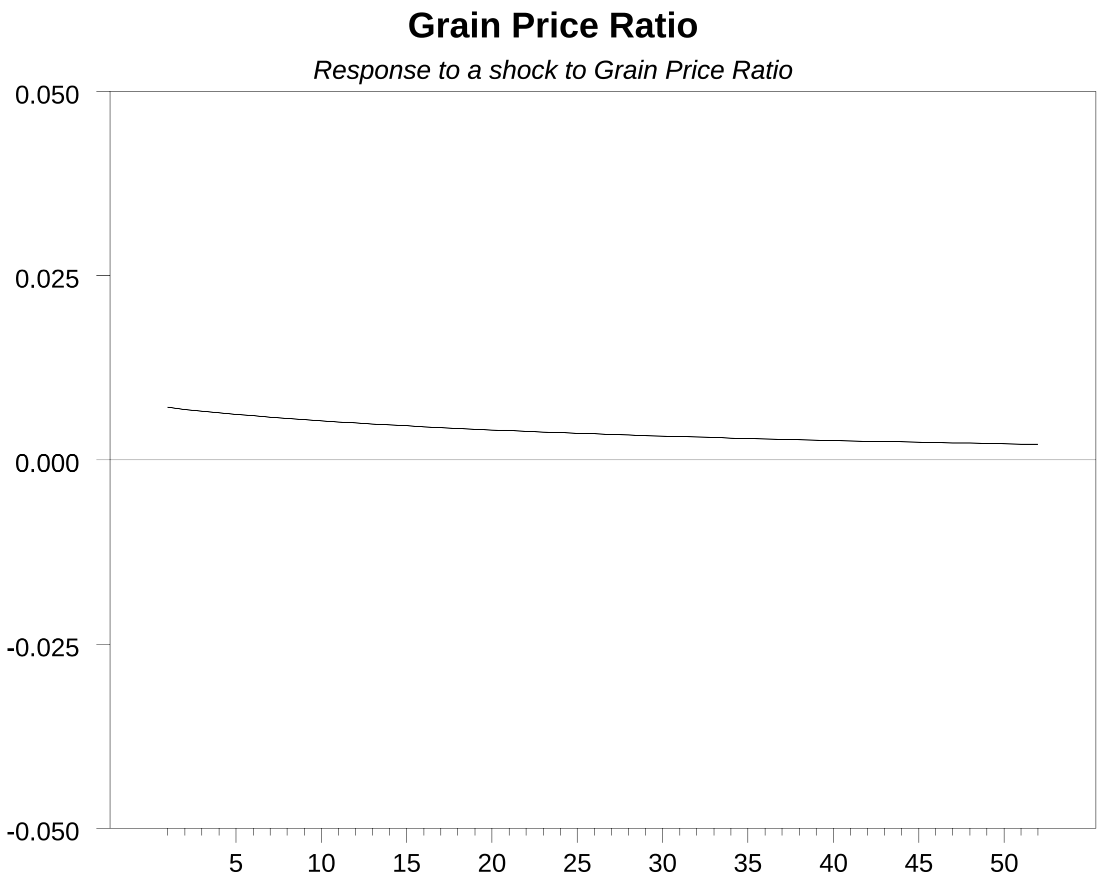


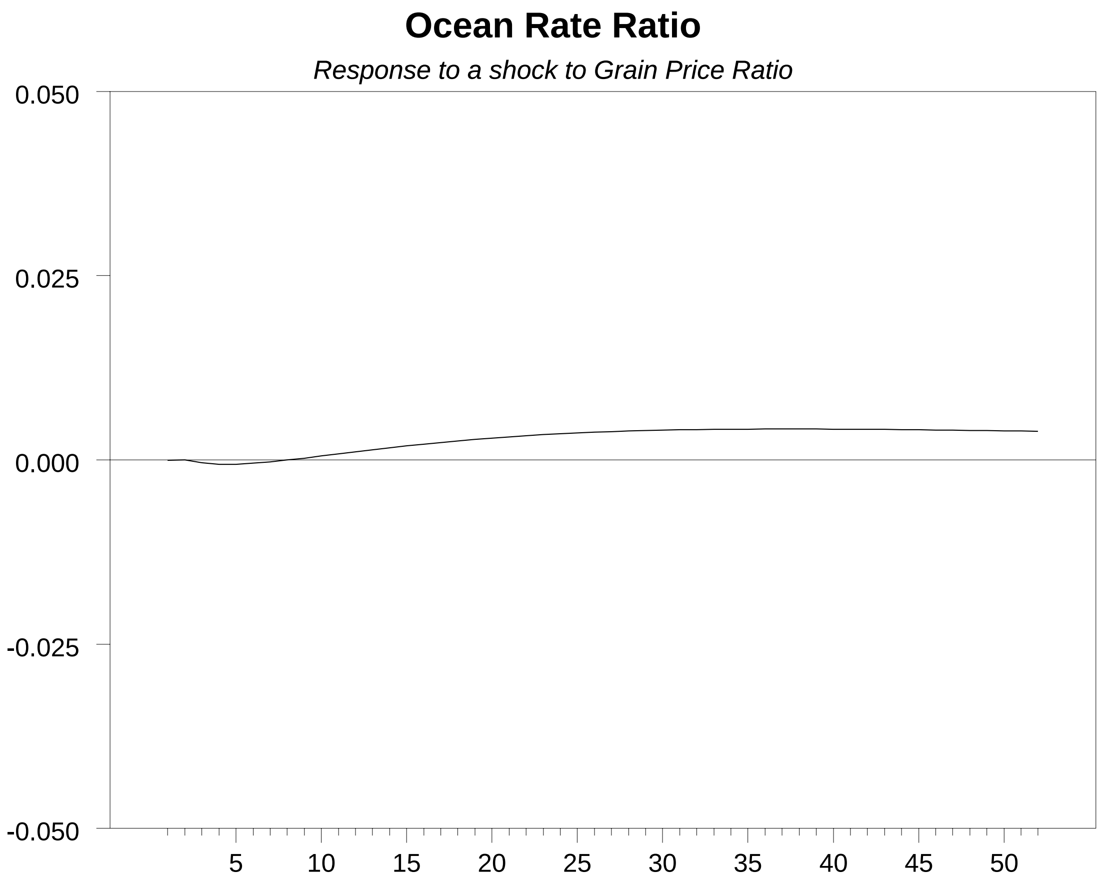
Miss. #27 Lockages
Response to a shock to Grain Price Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

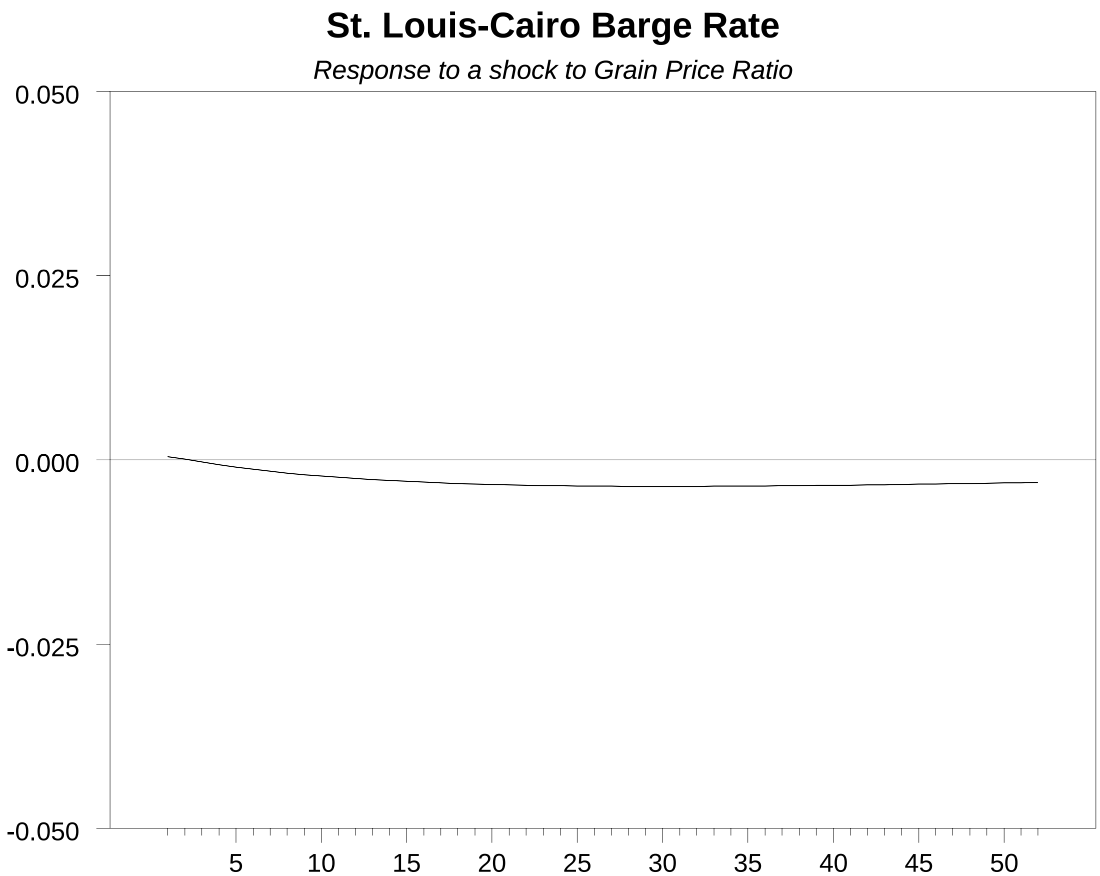


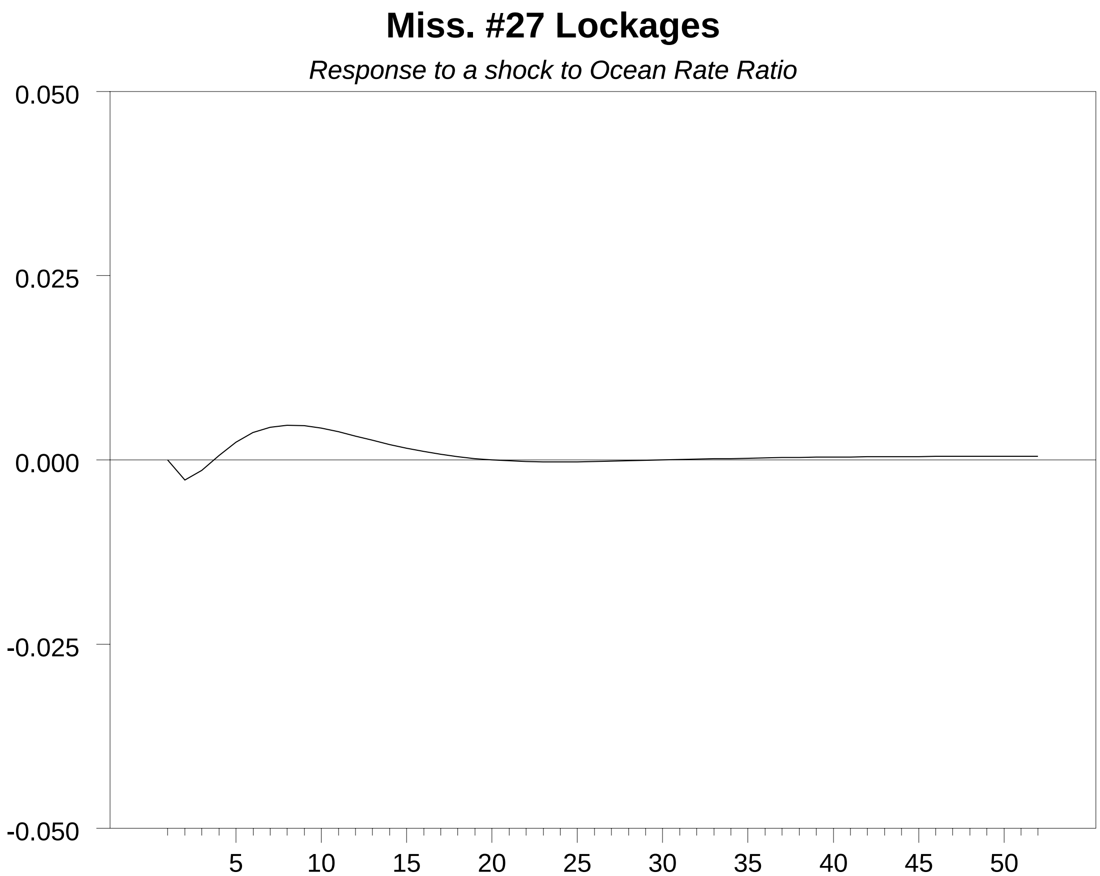
Rail Delivery Ratio
Response to a shock to Grain Price Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50


Rail Rate Ratio
Response to a shock to Grain Price Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

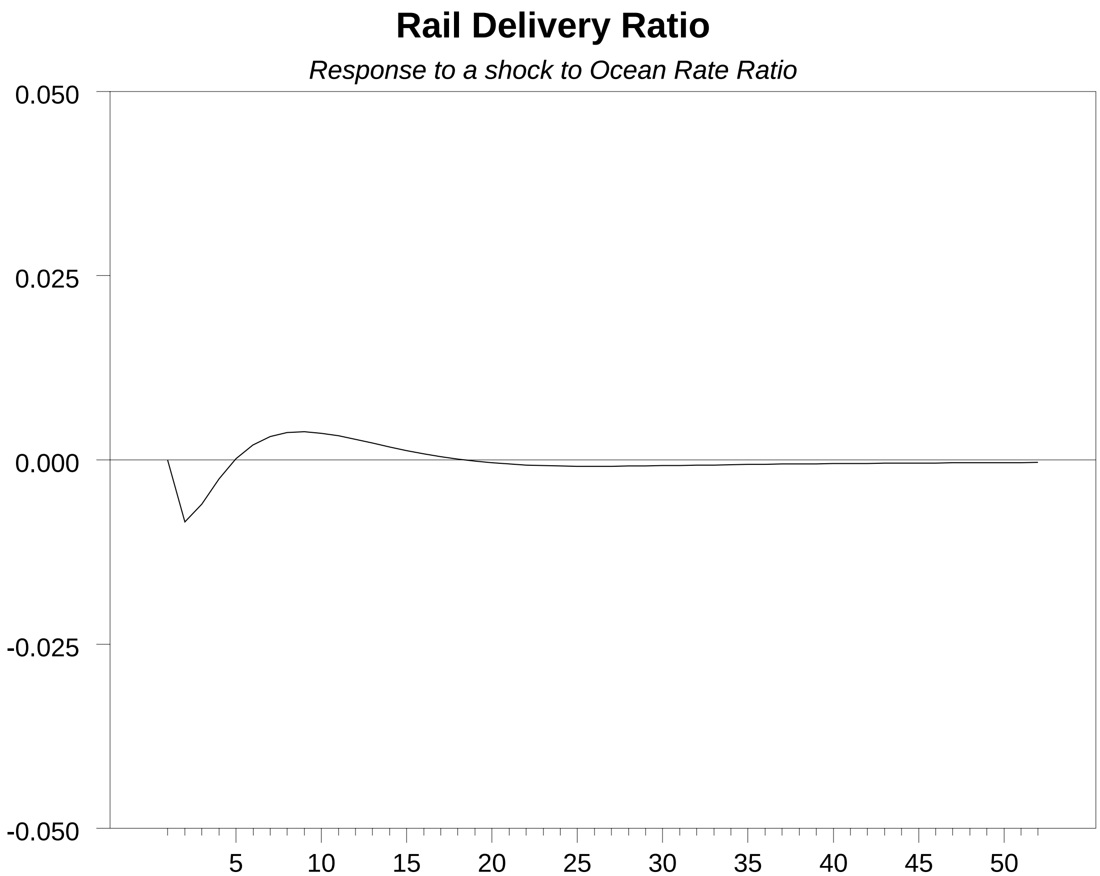

Grain Price Ratio
Response to a shock to Grain Price Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

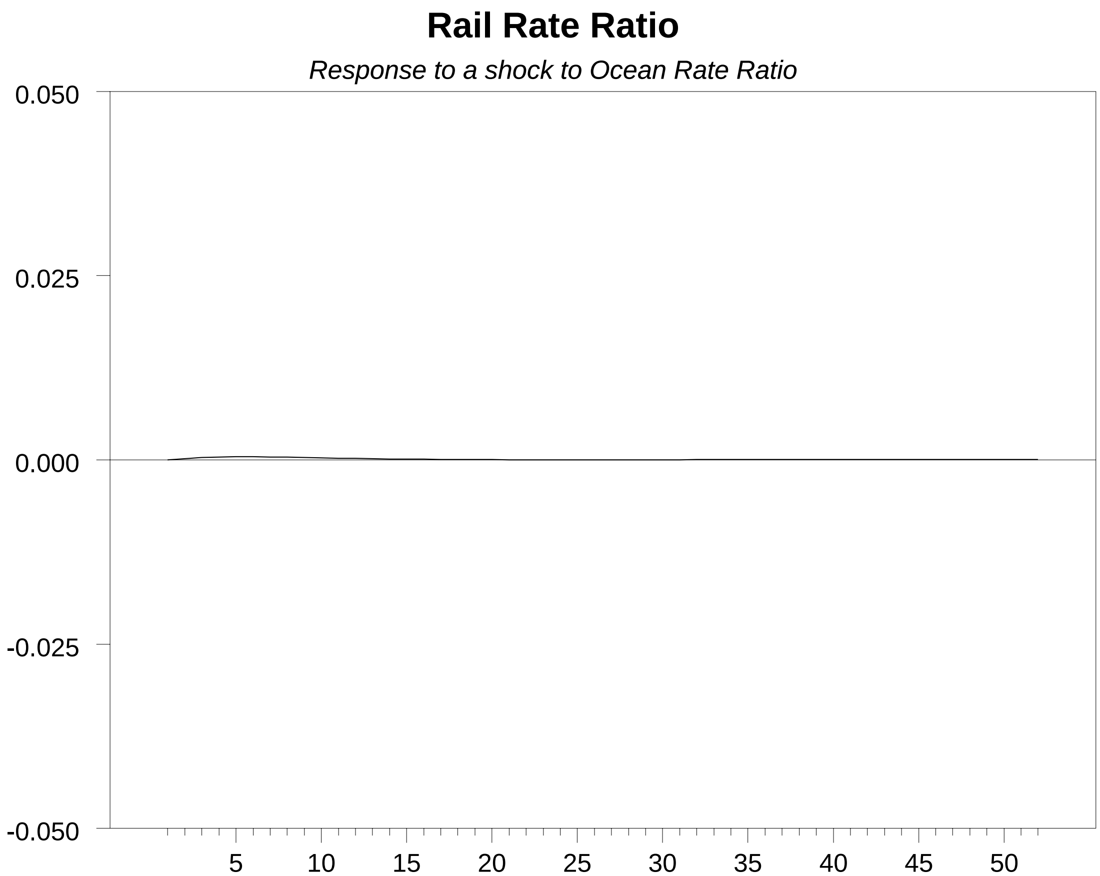

Ocean Rate Ratio
Response to a shock to Grain Price Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50


St. Louis-Cairo Barge Rate
Response to a shock to Grain Price Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

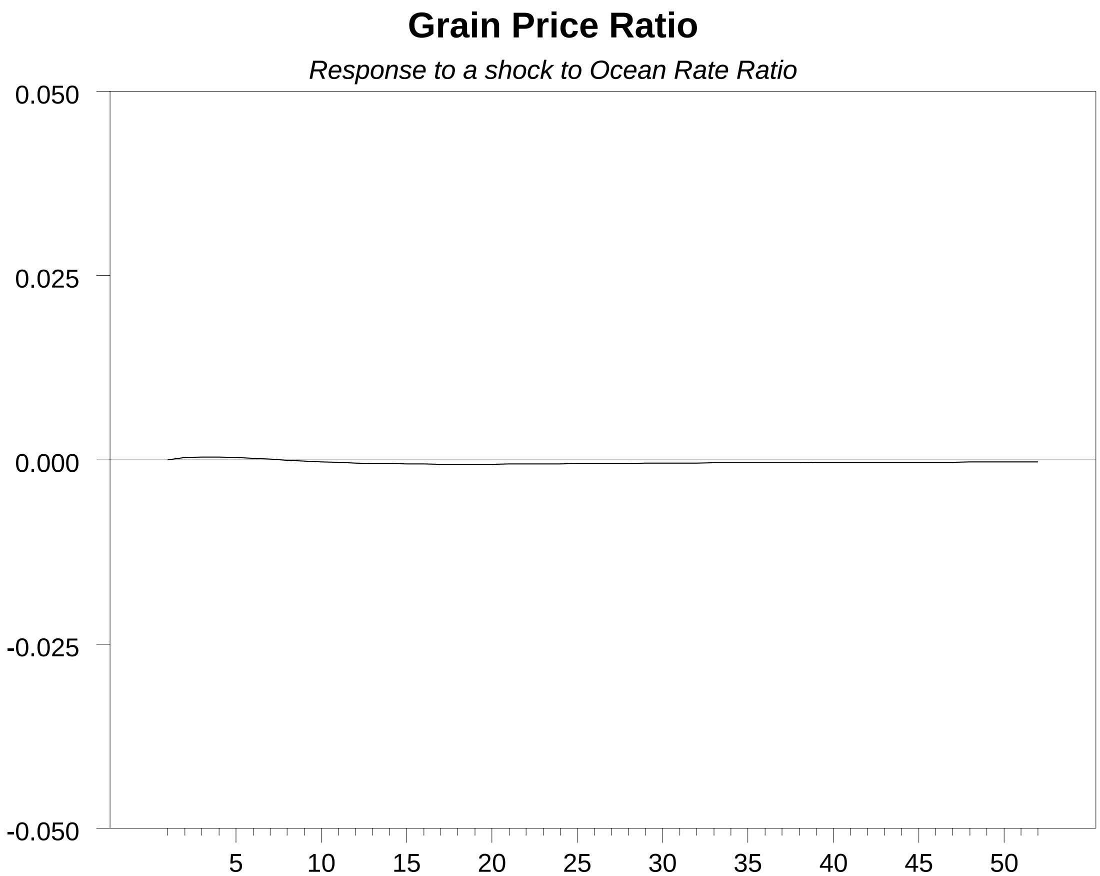


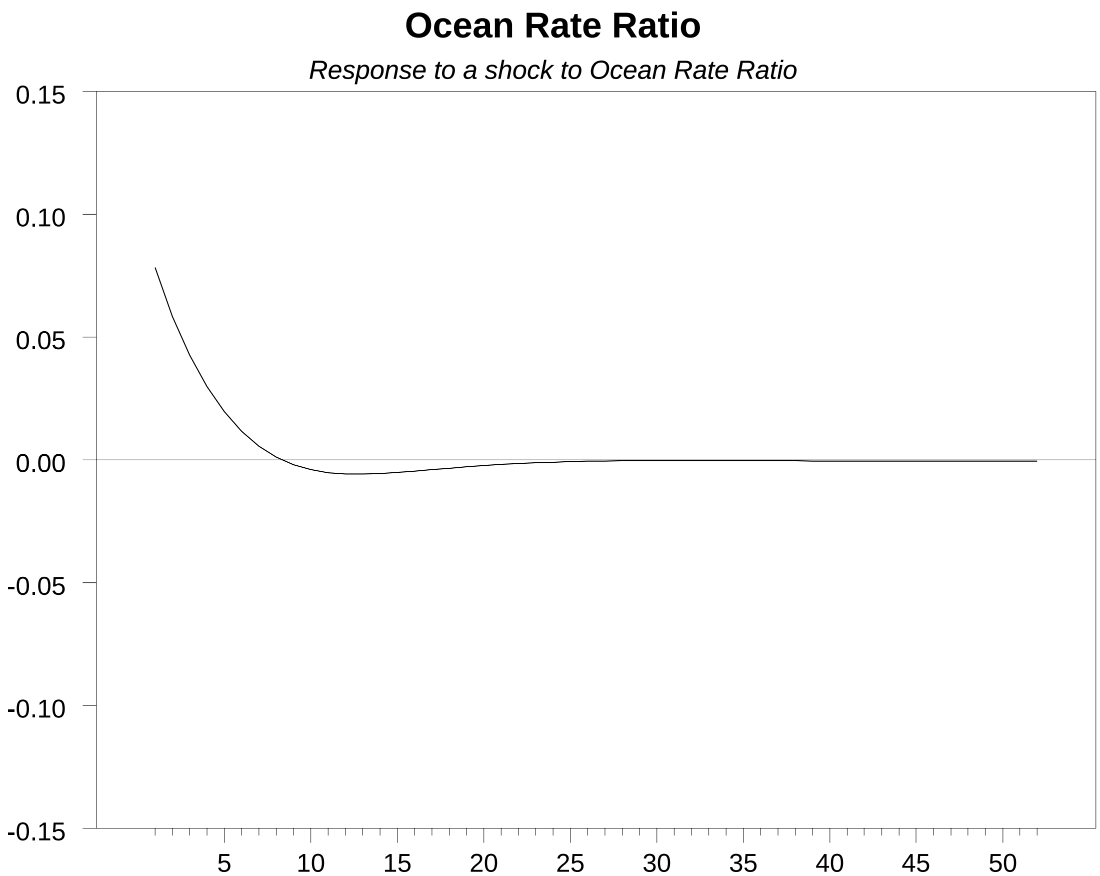
Miss. #27 Lockages
Response to a shock to Ocean Rate Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

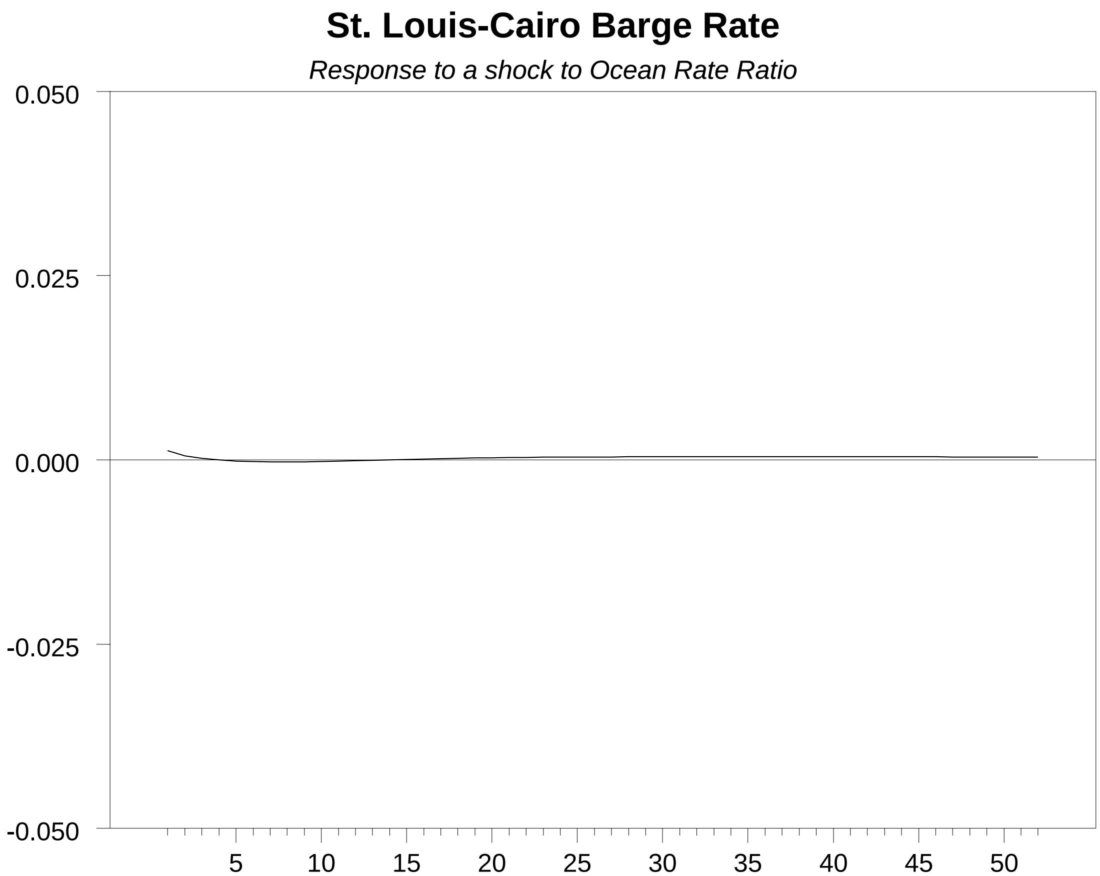

Rail Delivery Ratio
Response to a shock to Ocean Rate Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50



Rail Rate Ratio
Response to a shock to Ocean Rate Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

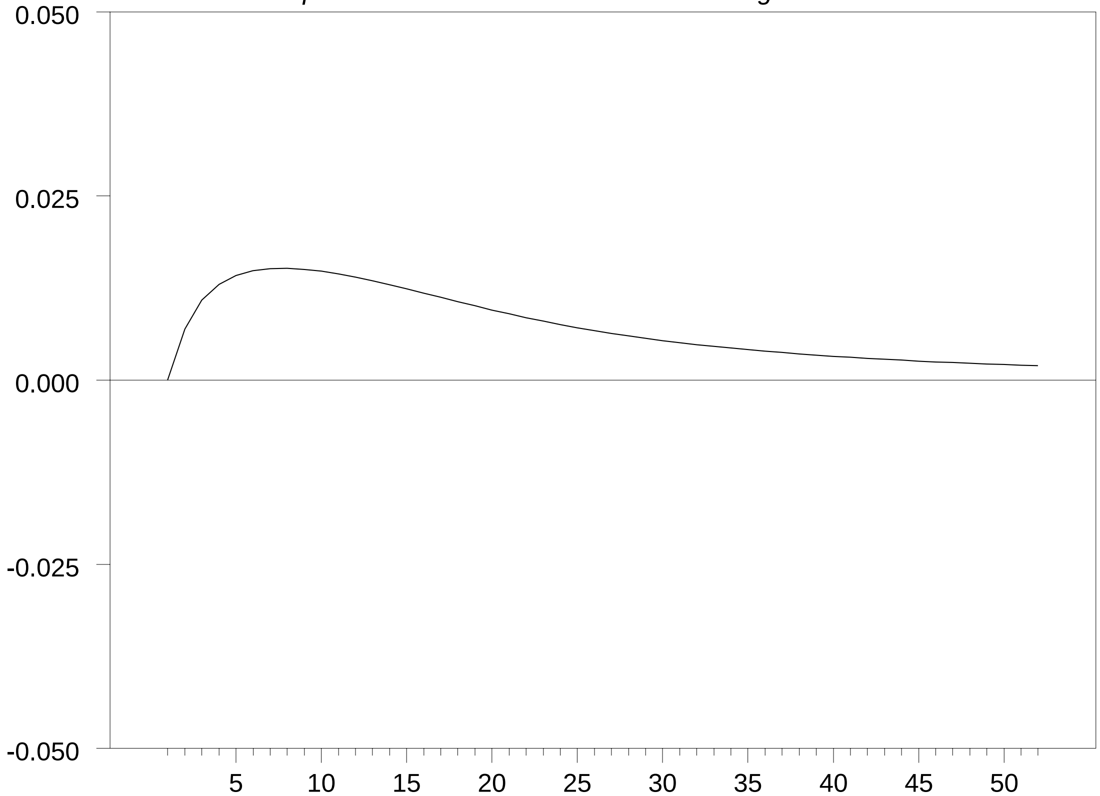

Grain Price Ratio
Response to a shock to Ocean Rate Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

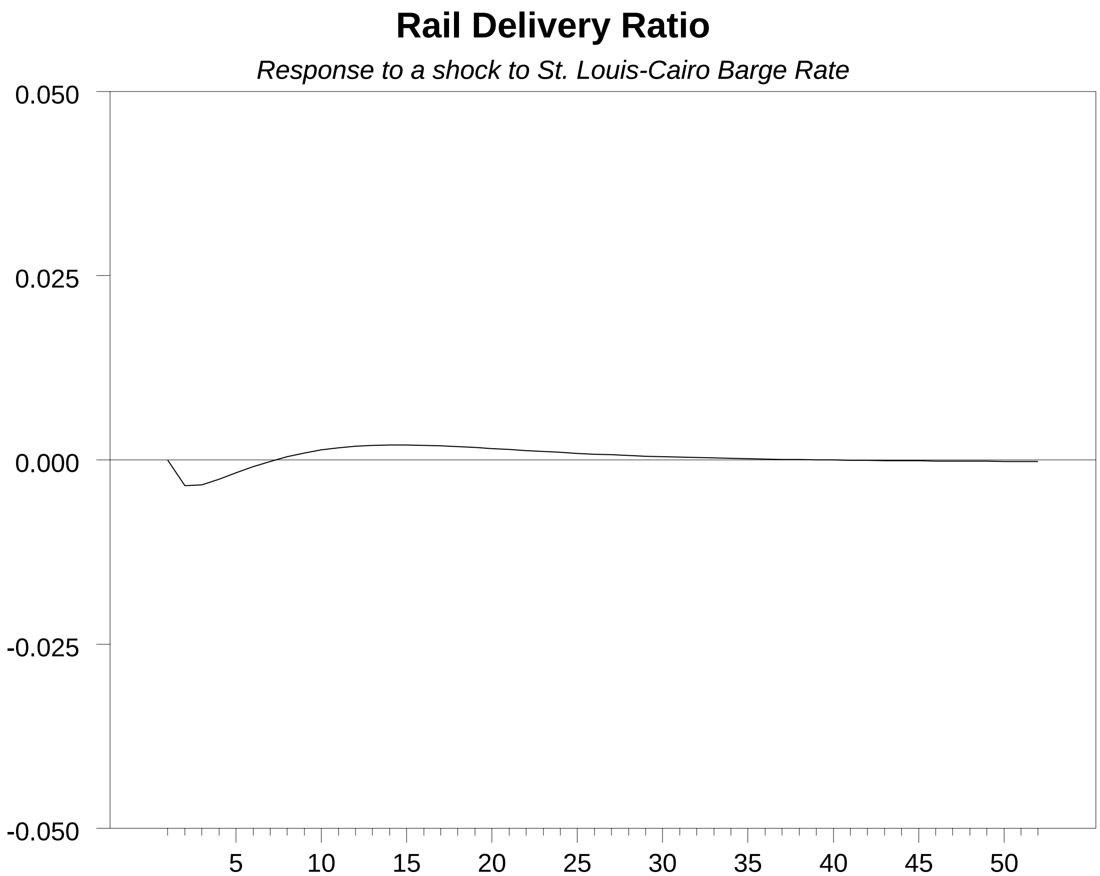

Ocean Rate Ratio
Response to a shock to Ocean Rate Ratio
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
5
10
15
20
25
30
35
40
45
50


St. Louis-Cairo Barge Rate
Response to a shock to Ocean Rate Ratio
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50

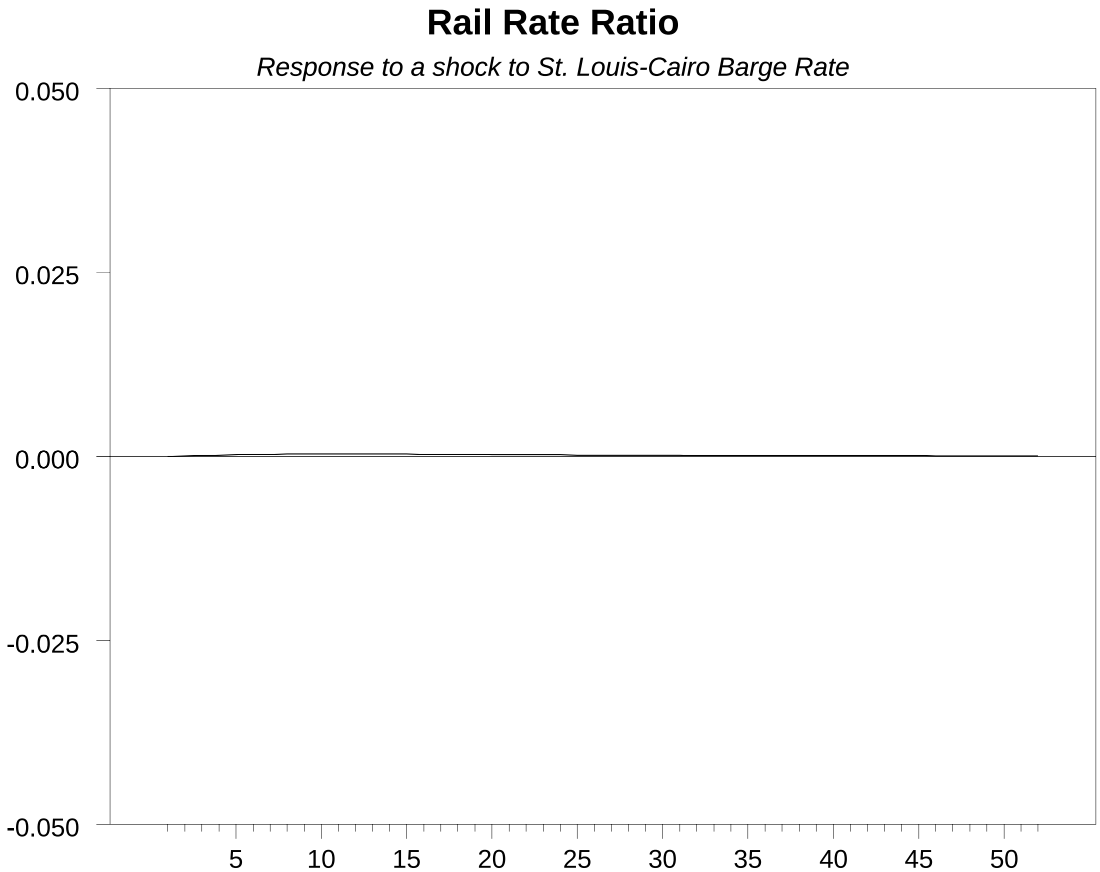
Miss. #27 Lockages

Response to a shock to St. Louis-Cairo Barge Rate





Rail Delivery Ratio
Response to a shock to St. Louis-Cairo Barge Rate
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
30
35
40
45
50


Rail Rate Ratio
Response to a shock to St. Louis-Cairo Barge Rate
0.050
0.025
0.000
-0.025
-0.050
5
10
15
20
25
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35
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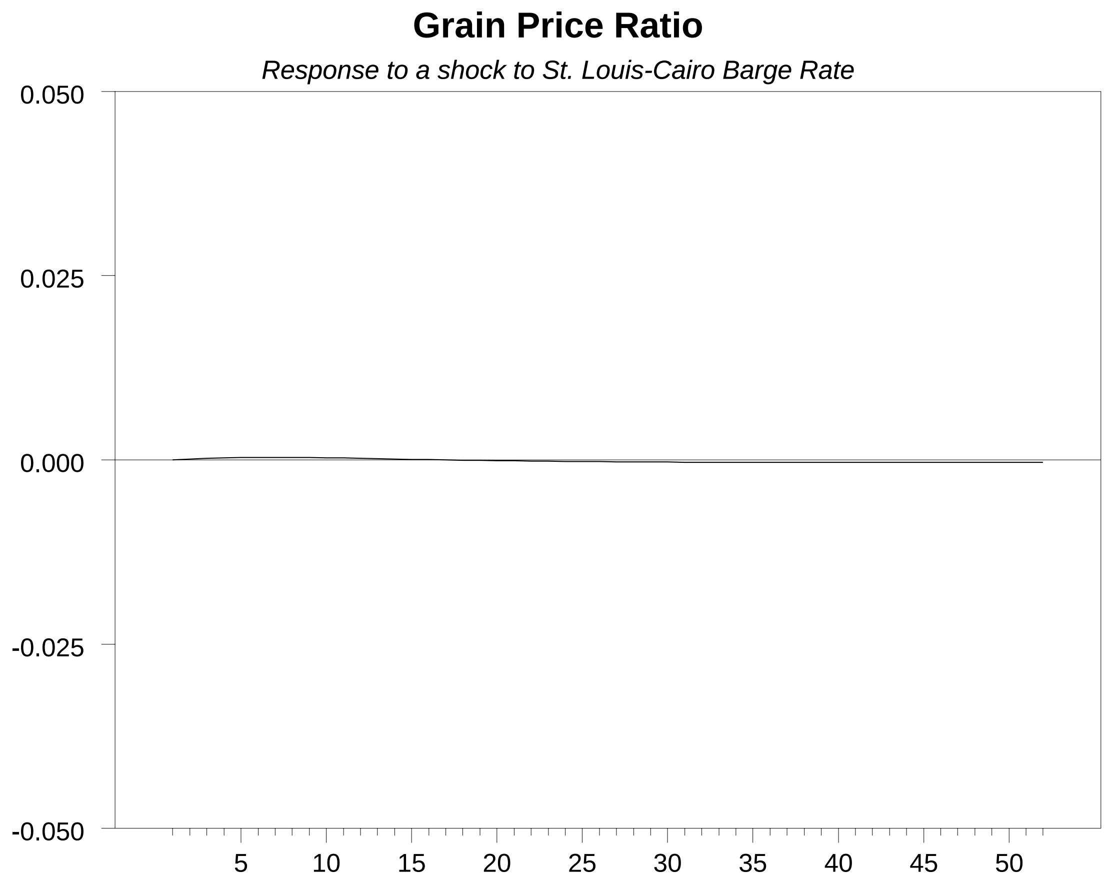
45
50


Grain Price Ratio
Response to a shock to St. Louis-Cairo Barge Rate
0.050
0.025
0.000
-0.025
-0.050
5
10
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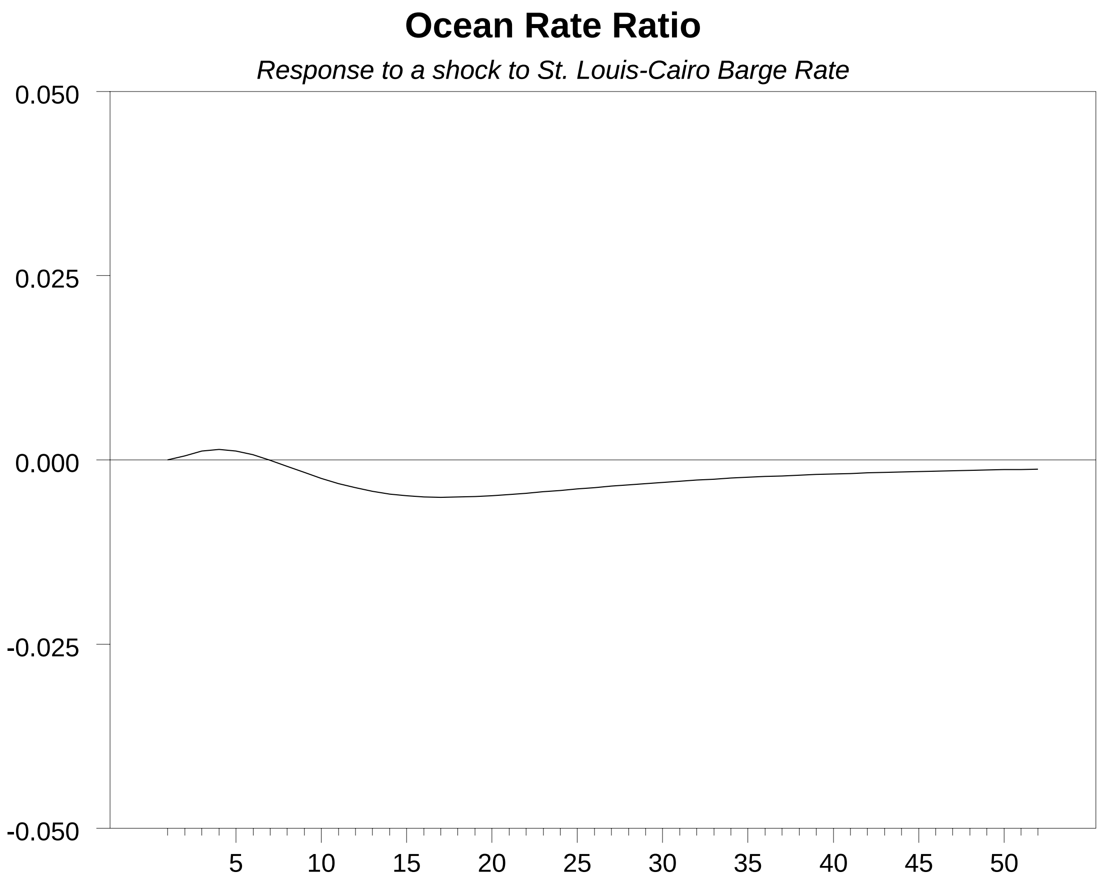
20
25
30
35
40
45
50


Ocean Rate Ratio
Response to a shock to St. Louis-Cairo Barge Rate
0.050
0.025
0.000
-0.025
-0.050
5
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25
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35
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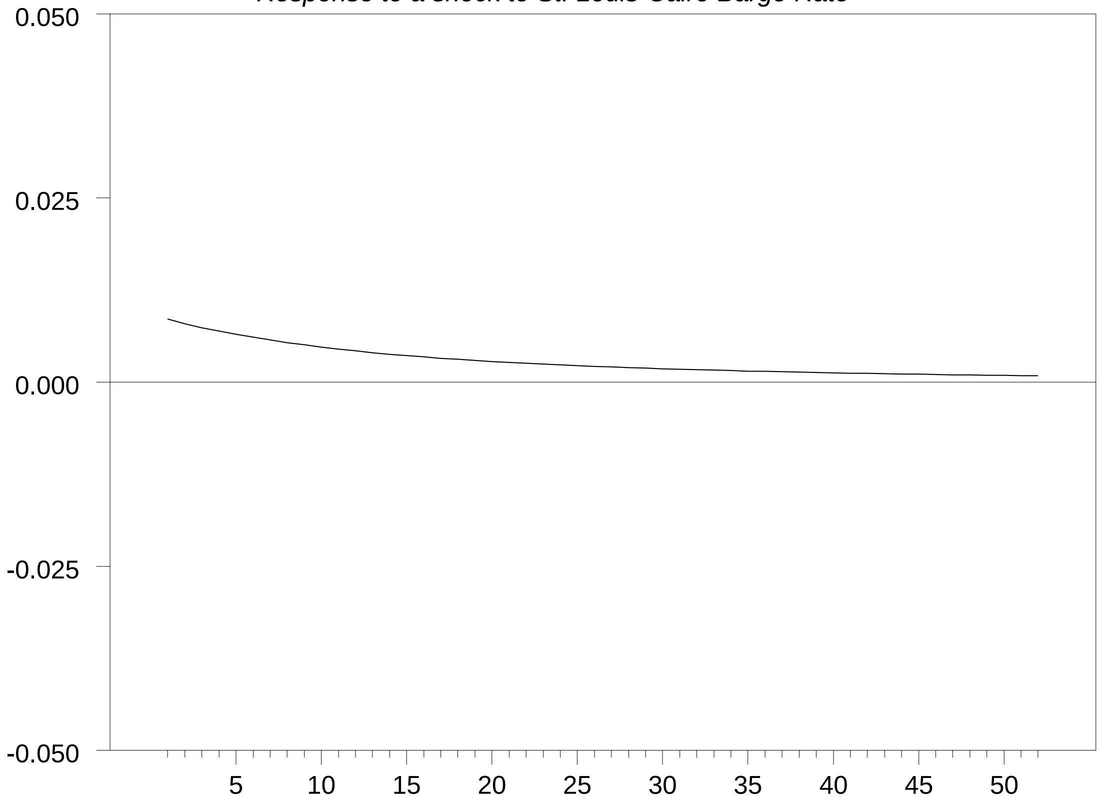
45
50

St. Louis-Cairo Barge Rate

Response to a shock to St. Louis-Cairo Barge Rate



NETS

navigation · economics · technologies

The NETS research program is developing a series of practical tools and techniques that can be used by Corps navigation planners across the country to develop consistent, accurate, useful and comparable information regarding the likely impact of proposed changes to navigation infrastructure or systems.

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.

As these models and other tools are finalized they will be available on the NETS web site:

http://www.corpsnets.us/toolbox.cfm

The NETS bookshelf contains the NETS body of knowledge in the form of final reports, models, and policy guidance. Documents are posted as they become available and can be accessed here:

http://www.corpsnets.us/bookshelf.cfm

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