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A Regional Market Model for Construction Aggregate Materials.

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A REGIONAL MARKET MODEL FOR CONSTRUCTION AGGREGATE MATERIALS

A Dissertation

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ABSTRACT

The primary objective of this dissertation is to model the regional markets for traditional construction aggregates, sand, gravel, and crushed stone.

The long-term dynamics of the construction industry related to the demand for aggregates is modeled through a partial adjustment mechanism. The dynamics of the construction industry is introduced into the estimation of a simultaneous equations model of the demand and supply for aggregates at district levels. An engineering-based cost function for extraction of sand and gravel is estimated based on data collected from an operators' survey in the states of Alabama, Arkansas, Louisiana, Mississippi, and Texas. A step-supply for each state is approximated by relating the estimated cost function to output for thirty six different mine types. Finally, regional trade is evaluated based on a multimarket spatial equilibrium model of the Samuelson-Enke type for a region of nine adjacent districts in the states of Alabama, Arkansas, Louisiana, Mississippi, and Texas.

Construction activity is found to depend on lagged values of construction activity, population, and changes in per capita income. Two-stage least squares is used to estimate supply and demand for aggregates. The empirical estimates show the demand for aggregates to be relatively inelastic to its own price, positively correlated to

construction activity, and positively related to construction workers wages. The long-run supply for aggregates is established elastic. Supply of sand and gravel is negatively related to the lagged price of crushed stone and vice versa.

The estimated engineering-based cost function shows operating economies in the sand and gravel industry. Geological factors are found to be important determinants of operating costs. A continuous approximation of the step-supply functions for extraction of sand and gravel is used to determine the short-run extraction supply elasticity, which is found inelastic.

No trade is found across districts at this time. Relatively high transport costs are believed to account for this result. The spatial equilibrium model's results are confirmed by the survey since on average 80% of the shipments travel less than 75 miles in 1991.

CHAPTER I

INTRODUCTION

I.1 Introduction and Problem Statement

The depletion of nonrenewable resources has become an increasing concern of modern society. Nonrenewable mineral resource availability depends largely on search and discovery of new reserves. There are several reasons why economic exhaustion of mineral deposits is a highly likely event. Urbanization, extraction costs, and transport costs can make some reserves economically unfeasible. Engineering research is being devoted to the development of recycle technologies in an effort to deal jointly with the eventual exhaustion of these resources and the increasing accumulation of industrial waste. However, once a recycled material is developed the important question of product demand remains an open one. The study of a new product demand can start by determining what traditional products substitute for recycled materials.

Recycled phosphogypsum based materials are believed to be substitutes for traditional construction material such as sand, gravel, and crushed stone. Sand, gravel, and crushed stone are the largest nonfuel mineral commodities, by tonnage, produced in the United States. They supply some of the most critical construction materials (Tepordei, 1989). These traditional construction materials are subject to the

availability of exhaustible mining deposits and recycle. Sand and gravel are used as inputs in the construction of highways, buildings, fill, and several other outputs. Crushed stone is a substitute for gravel in some uses. Sand, gravel, and crushed stone are not homogeneous, varying in size, shape, strength, roughness, etc. Different applications require different material specifications.

Sand and gravel are geologically defined as unconsolidated mineral and rock particles that in most cases have been transported by water and abraded so that their edges are rounded or dulled (Committee on Surface Mining and Reclamation, 1980). Crushed stone is usually mined from rock masses and crushed to marketable sizes. Shortage of sand and gravel can be covered by manufacturing fine aggregate from crushed stone.

Sand and gravel are excavated without blasting, and below water the material may be excavated by various types of dredging equipment. The material is usually carried to plants by trucks, conveyor belts, or private railroads, where it is cleaned, separated, and stored. In some locations in the U.S. crushed stone is also excavated from below water by dragline. The means of moving stone to plants are similar to those used by the sand and gravel industry. Sand and gravel and crushed stone plants resemble each other because the washing and screening processes are similar. However, since stone must be crushed, crushing

equipment is much more important for stone plants. Since the major cost is getting the processed product to the consumer (i.e., transportation costs), the quality and quantity of a given deposit may be irrelevant when transportation costs are too high.

The demand for construction sand and gravel is derived from its ultimate use, construction. In the West South Central Region, which includes Louisiana, 56.5% of the gravel is used as concrete aggregate (buildings, highways and streets, etc.), 16.6% is used as roadbase and coverings, 13.1% is used as fill, 8.5% is used in asphaltic concrete and bituminous mixtures, and the remaining 5.3% has miscellaneous uses (U.S. Bureau of Mines, Sept. 1981). The use of sand and gravel will depend upon the level of construction activity. The sand and gravel materials in a construction project are likely to comprise a small portion of total project cost. As a result, we would expect that the demand for sand and gravel would not be highly dependent upon the prices of sand and gravel materials. Even though crushed stone and sand and gravel can generally be used for the same purposes, they have individual characteristics that allow producers of both to coexist and produce for the same markets. For most concrete, natural fine aggregate (sand) is preferable to crushed fine aggregate; but crushed stone is often superior to natural gravel for some coarse aggregate uses such as jetty rock and

riprap (Committee in Surface Mining and Reclamation, 1980). The 5 leading companies in the U.S. (producing 13.8% of the U.S. total) own sand and gravel pits as well as crushed stone quarries (Rock Products, 1989).

Aggregate markets are likely to have important spatial delineations due to high transport costs relative to the mineral value. For example, a typical, 1,500-sq-ft house requires about 115 tons of aggregate, mostly for the foundation. Trucking 115 tons of aggregate a distance of 25 miles in Southern California costs about $300. If the distance increases to 60 miles, the shipping cost become about $700, more than the cost of the aggregate, which at $5.5 per ton costs $632 (Tepordei, 1989). Spatial aggregate markets will overlap but not to the extent of the entire state being considered a one large market. North Louisiana is not likely to ship much gravel to South Louisiana, and vice versa, unless gravel becomes very scarce in one region or another. Even though high volume transport by rail or water carrier is possible, the implication is that there will be well defined geographic market areas with the degree of independence of supply and demand conditions prevailing in those markets depending upon transport costs. Evidence for market independence would be considerable variations in materials prices, both at the delivered and fob (free on board, or mine mouth) levels. For example, in 1989 average gravel prices were $9.00 per ton (fob) in Shreveport,

Louisiana, where gravel is scarce, while they were only $4.50 per ton (fob) in the Louisiana Amite basin area where gravel is more abundant (Amite River Basin Commission, unpublished report, 1991). However, markets will not be totally independent since supplies to one market will be partially dependent upon prices and profitability to suppliers of delivering material to other markets. Market scarcities and reductions in transport costs will expand the spatial dimensions of gravel markets.

Quantity supplied and prices in metropolitan markets are subject to the availability of mining deposits and high transport costs. The availability of aggregate reserves is limited locally and subject to increasing extraction costs as the most efficient reserves are mined first. Deposits vary with respect to the cost of extraction and quality of the mined material. Extraction cost will depend upon the configuration and location of the deposit. Site preparation costs will vary with the nature of the overburden. Extraction costs will vary with mining technique used as well as the width and depth of the deposit. The quality of mined material, particularly the ratio of sand to gravel, will have a great effect on the processing cost per unit of commercially marketable material since sand typically has a much lower market value than gravel, and is often just waste.

The definition of "a market" for these materials becomes crucial under the above mentioned considerations. An operator will truck the product to metropolitan centers but within a limited area. The decision to ship to one of many alternative metropolitan areas is determined by the prevailing price in the market areas, the distance between the mine and the market, and the transport costs. The Bureau of Mines has recently recognized the importance of the market definition and has redesigned its reporting system to more accurately reflect real markets for production data. Forty states have been divided into several districts each by grouping adjacent counties.

The sand, gravel and crushed stone industries are represented by a large number of companies and operations. A total of 6,082 companies were operating in the U.S. during 1986 and 1987. Nationally, industry concentration is not high, with the five leading crushed stone companies producing only 19% of the US output of crushed stone, while the five leading sand and gravel companies produced only 7% of the total US output. At the local market level, concentration is higher, as we would expect for a spatially segregated industry. For example, in the Louisiana Amite River Basin there were 34 different sand and gravel producing firms, with the top 4 accounting for one-half the employment (Governor's Interagency Task Force on Flood Prevention and Mitigation, 1992).

U.S. sources of construction aggregate are still sufficient for most of the country. Imports represent less than 0.5% of the U.S. consumption and they have been limited to mostly localized transactions across the international boundaries (Tepordei, 1989). Emerging market supply sources in the South Central region of the U.S. include shipments of crushed limestone from the Bahamas and Scotland to the Gulf Coast, and from the Yucatan peninsula to some locations in Alabama.

I.2 General and Specific Objectives

The major goal of this study is to model markets for aggregates in order to anticipate materials shortages and surpluses in various geographic markets. Knowledge of clearing prices, quantities, and trade flows on the traditional construction materials' markets (sand, gravel, and crushed stone) should prove vital to suppliers of recycled phosphogypsum construction materials when deciding whether a particular district area is feasible to enter.

The general objective of this research is to model the markets for aggregates (sand, gravel and crushed stone)[1]. Specific objectives are:

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[1] In the southern portions of Louisiana and Mississippi, crustal shell is used as construction material. Since this study is based on data for the entire country, crustal shell is not included.

a) Model the long-term dynamics of the construction industry related to the demand for aggregates.

b) Estimate the demand and supply for aggregates at meaningful market levels.

c) Estimate an engineering-based cost function for extraction of aggregates.

d) Evaluate aggregates regional trade based on a multimarket spatial equilibrium model.

This study does not, however, attempt to address the important issue of market acceptance of phosphogypsum materials. That is, Will the market accept phosphogypsum based materials as substitutes for traditional aggregates?

I.3 Justification of the Research

Phosphogypsum based aggregate materials have physical properties which make them potential substitutes for traditional aggregates (sand, gravel, and crushed stone). Unlike markets for more valuable minerals, markets for aggregates have received no specific attention in past research. Reasons for this may be the historically low price and relative abundance of these minerals. Other markets, such as copper, iron ore, and petroleum, have been modelled extensively (see Krautkraemer, 1989; Rowse, 1988; Wilkinson, 1983; Zimmerman, 1986; Balestra and Nerlove, 1966; Toweh and Newcomb, 1991). The phosphogypsum industry is expected to benefit from this study since an economic

model of the traditional construction materials markets (supply and demand relationships) will be quantified.

I.4 Organization of the Dissertation

The dissertation is organized in seven chapters. Chapter II presents a review of relevant research. Chapter III presents the theoretical models. Chapter IV presents the estimation of the model for aggregate markets under the no-trade, or autarchy, scenario. These results in estimates of: 1) a time series model of construction demand and 2) a cross sectional simultaneous equation model of supply and demand for these aggregate materials. Chapter V contains the estimation of engineering-based costs functions and the corresponding step-supply functions for aggregate extraction for a five states area: Louisiana, Texas, Alabama, Mississippi, and Arkansas. Chapter VI uses the estimated model from Chapter IV to establish market clearing prices, quantities, and trade flows. Chapter VII summarizes major findings, presents conclusions, and outlines recommendations for future research.

CHAPTER II

REVIEW OF LITERATURE

II.1 Introduction

This research is directed towards the study of a group of nonrenewable mineral resources generally known as aggregates. Mineral resources can be divided into two major types by uses: energy supplies and nonenergy supplies (Hartwick and Olewiler, 1986). Energy supplies are dissipated upon use by conversion of matter to energy. Nonenergy minerals preserve their structural properties and simply become a part of the composition of other goods. These minerals are often highly durable even though the goods using them have varying durability; for example, steel and razor blades, diamonds and rings, copper and electrical wiring. Aggregates primarily become embodied in construction materials. The demand for aggregates is related to changes in the stock of capital infrastructure.

Studies of nonenergy minerals markets have varied greatly in sophistication. Simple assessment of trends in supply and demand conditions can be found in Minerals Yearbooks, and in more specific publications like Mineral Commodity Profiles and Rock Products. An example is Evans (1978) study of sand and gravel. He assessed issues related to industrial structure, principal sources of demand and supply nationally and worldwide, mining technology, and

capital requirements. More recently, Tepordei (1989) offered a historical perspective of the sand and gravel and crushed stone industries, and an assessment of expected future demand.

Robertson (1989) reports the findings of a nationwide producers' cost survey conducted by the magazine Rock Products in 1988. A summary of their findings on cost shares is shown in Table II.1.

Table II.1

Share of Mining Cost in Sand and Gravel and Crushed Stone Industries

Cost Source	SAND AND GRAVEL	CRUSHED STONE
Energy	10%	12%
Drilling and Blasting		14%
Dust Control	1%	2%
Hauling	15%	7%
Loading	23%	11%
Maintenance	13%	19%
Processing	20%	29%
Reclamation	4%	2%
Stripping	14%	4%
	100%	100%

On a national average, approximately 63% of the crushed stone producer's budget goes toward extraction, processing, and materials handling while a sand and gravel producer spends 64% of his mining cost for these categories.

The copper industry underwent more sophisticated analysis during the 1980s (Wagenhals, 1984; Tan, 1987). These studies addressed three major topics: 1) supply of the mineral resource; 2) demand for the mineral resource; and 3) development of a trade model. The remainder of this chapter

will focus on these three issues. These two studies will be considered in depth below.

II.2 Supply Side Modelling

Nonrenewable resources share a common theory of depletion. A mine manager must determine not only how to combine factors of production, but also how quickly to run down the fixed stock of resource in the mine. The theory of depletion dates from Gray (1914), who assumed that the market price of a unit of mineral remained constant over the life of the mine and the producer knew the exact amount of reserves prior to extraction. The seminal work of Hotelling (1931) examined the optimal extraction of a nonrenewable resource. Both Gray and Hotelling arrived at the same condition for the efficient extraction of a mineral: the present value of a unit of a homogeneous but finite stock of the mineral must be identical regardless of when it is extracted. Hotelling studied the rate of extraction under alternative market structures and determined that a competitive industry initially exploits the resource at a higher rate, and ultimately exhausts the resource more rapidly than the monopolist. The first substantial step beyond Hotelling was taken by Herfindahl (1967) who considered the optimal extraction profile of a competitive firm with constant cost deposits of different quality. Herfindahl showed that the deposits will be worked in

sequence, beginning with the lowest-cost deposits. Pindyck (1978) made the distinction between exhaustible and nonrenewable resources by noting that the later do not exhibit growth or regeneration, but new reserves can be acquired through exploratory effort and discovery. Excellent treatment of the theory of the mine and the modelling of resource extraction can be found in Kemp and Long (1980), Hartwick and Olewiler (1986), or Conrad and Clark (1987).

Models of the short-run supply must focus on the economic variables that determine producer behavior. Empirical work has been focussed on three different perspectives: 1) Studies that model the supply, based primarily on the relationship between costs of production and geological characteristics; 2) Models of the behavior of the producer at points of delivery, abstracting from geological considerations; and 3) Models which incorporate both mine mouth and delivery, usually involving large scale econometric models. Each of these is discussed below.

The first group includes the comprehensive efforts undertaken by the Federal Energy Administration during the 1970s and early 1980s. These studies focused on energy supplies (oil, gas, and coal). They developed a procedure that relates costs to geological characteristics and production. This procedure can be used to establish mine mouth supply for these fuels. This work culminated in two

sets of models: the Project Independence Evaluation System (PIES); and the Resource Allocation and Mine Costing Model (RAMC). Both will be described below.

The PIES supply model for coal was a step supply engineering estimation based on per unit costs. The step supply is calculated as the minimum acceptable price at which a coal company would recover all of its costs plus earn an eight percent return on its investment, therefore it was a long run supply. Each step represented the development of a different mine type. The price attached to each step was the minimum acceptable selling price at that particular mine type. The production level associated with each step was the maximum annual production that the Bureau of Mines' "Demonstrated Reserve Base" could sustain from that particular mine type for 20 years. The costs of mining were estimated as functions of overburden ratio and mine size for the surface mining; and seam thickness, seam depth and mine size for underground mining. The step supply curves were developed under the assumption that step functions are good approximations of the long-term supply relation.

The RAMC was an engineering process model used to provide coal supply curves for a set of pre-defined coal types and producing regions. It developed mining cost estimates based on capital costs, operating costs, and overburden ratio. There were separate versions of RAMC for

surface mining and underground mining. The purpose of these supply curves was to establish the availability of coal reserves at selected selling prices. The estimated step-supply relationships were then used in the National Coal Model (NCM) and the Coal Supply and Transportation Model (CSTM) to determine the minimum cost transportation routes.

The approach to modelling the supply side from a short run perspective, has been to abstract from geological considerations and decisions regarding investment. These studies concentrated purely on the market conditions that the producer faces in the short-run. Delivery supply is assumed to be perfectly elastic. Justification for this included price regulation for some energy supplies and substantial stock piling. Balestra and Nerlove (1966) assumed perfectly elastic supply for natural gas based on the regulated price argument. Toweh and Newcomb (1991) based their perfect elasticity assumption on the reasoning that aggregate regional production and market conditions were determinants of prices in iron ore, so local prices are exogenous. In any case, the results of the supply elasticity assumption is that only local demands needed to be modelled.

A third approach to modelling supply has been to represent mine production as well as delivered supply. Wagenhals (1984) developed an econometric model for the world copper market that contained primary supply functions

derived from restricted profit functions and a dynamic stock disequilibrium approach. Copper mine production capacities were endogenously determined and the modeling of private inventory behavior used a rational expectations approach. Tan (1987) conducted a similar study on the world copper market over a slightly different period of time, specifically modeling stockholding and its relationship to price formation. Both Wagenhals and Tan estimated the supply side of the model separately from the demand side. Rice and Smith (1977) developed a nonlinear forty-two equation model of the U.S. petroleum industry estimated over the period 1946-1973. Their model specified refinery outputs and prices as being simultaneously determined by market forces while the domestic output of crude oil was determined in a block-recursive segment of the model. The supply side was modelled by specifying that the price of each refinery product was a function of quantity supplied, the weighted average price of domestic and foreign crude, the ratio of the relative yield of each product to that of gasoline, and the average price of crude. Their model contained stochastic behavioral equations for drilling activities. Domestic production was derived from the identity existing between reserve additions and changes in the reserve stock.

II.3 The Demand for Nonrenewable Resources

The demand for a nonrenewable resource derives directly from its ultimate uses. Oil, gas, and coal demand are derived from energy uses. We can think of energy use as being related to the stock of capital in existence; for example, the stock of gas appliances (Balestra and Nerlove, 1966) or vehicles. Other mineral demands, such as copper, iron ore, and aggregates, are related largely to changes in infrastructure stock. For example, Construction of roads, buildings, etc. are reflections of actual changes in infrastructure stock.

The partial adjustment model is a reasonable framework for modeling demands for goods related to changes in capital stocks[1]. The basic idea is that the "desired" level of capital stocks is determined by the current value of a set of independent variables. However, only some fixed fraction of the gap between actual and desired stocks is achieved in one period (Judge et al., 1985). The partial adjustment specification has been used in a wide variety of empirical applications including the modelling of stock adjustment of mineral reserves (Rice and Smith, 1977).

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1 The partial adjustment model was developed by Nerlove (1956) and for detailed specification the reader is referred to Judge et al. (1985), Greene (1990), or Harvey (1991).

II.3 Market Models with Trade

Aggregates markets are spatially segregated, as are many other mineral markets. The existence of price differentials, even after adjusting for transportation costs, induces trade across states, regions, or countries. However, in order to model trade, an initial equilibrium between supply and demand conditions without trade must first be determined. Many of the studies that we reviewed in previous sections were not developed with simultaneous determination of supply and demand.

In many cases, specific algorithms were developed for the determination of the market equilibrium. The PIES market equilibrating algorithm joins, independently estimated demand functions (linear or log-linear), a supply sector represented by a cost-minimizing linear programming problem, and a market equilibrating algorithm that searches for a market equilibrium by solving a sequence of optimization problems. The equilibrium clearing price is found by measuring the area of consumer plus producer surplus. When that area is maximized, the market clearing price has been found. Conditions for the existence of and uniqueness of equilibrium solutions of the PIES algorithm are offered by Ahn (1979).

Several studies had the sole objective of finding equilibrium after trade without assessing the pre-trade equilibrium condition. These studies used linear programming

to find trade flows. One of the earliest applications of this type was that of Henderson (1958). He studied the efficiency of the coal industry using a linear programming algorithm in a transportation model. Regional demands where fixed and supplies where represented by a fixed short-run capacity with constant cost of extraction up to capacity. By introducing the unit transport cost between demand and supply regions, he solved a linear programming transportation model to determine shipments across regions.

In the NCM and the CSTM, demand is also assumed fixed and the objective is to find after trade clearing prices by introducing transportation costs. These models used the step supply curves estimated by the RAMC. The NCM's objective function was to minimize total cost of mining, coal transportation, and electricity generation. The CSTM developed a higher level of sophistication since the RAMC step supply curves are converted into piecewise linear functions. Demands were still assumed fixed. The CSTM is an iterative procedure that starts from production and transportation set to zero and discovers the least-cost transportation paths. The PIES also has a transport component where excess supply regions are connected to excess demand regions through transportation costs, and flows are determined by minimum transport costs.

The formal problem concerning equilibrium among spatially separated markets was first formulated by Enke

(1951). The transportation and linear programming models were the first, but the simplest and most restrictive, solutions to the problem of quantifying trade flows. Samuelson (1952) first presented the equilibrium condition among spatially separated markets as a mathematical program, by defining a welfare measure that he called Social Pay Off(SPO). SPO measures the welfare gains of exporting excess supply or importing excess demand. When transportation costs are subtracted the objective function is Net Social Pay Off, which can be maximized.

One of the restrictive features of linear programming is that it cannot deal with demand and supply relationships explicitly formulated as linear relationships between quantities and prices since the objective function becomes non-linear. Takayama and Judge (1964) developed a quadratic programming algorithm for the Enke-Samuelson type problem. It has found extensive empirical applications in mineral markets and agricultural commodity markets (Heady and Srivastava, 1975).

Toweh and Newcomb (1991) published a study of the world iron ore trade based on the idea of spatial equilibrium analysis. Their model determined the trade flows that maximize social pay off minus the transport costs of delivered materials. They compared the estimated flows to the actual shipments for 1984. The Toweh and Newcomb study used Takayama and Judge (1964) quadratic programming primal-

dual approach where for each region supply is fixed and demand quantities are linear functions of price. They calculated the efficiency of the estimated model following Henderson (1952). The estimated flows explained 79% of the interregional flows, 79% of the average delivered prices, and 91% of demands.

The Enke-Samuelson specification is based on perfect competition, since net welfare gains are maximized. The theoretical underpinnings of this model have been challenged (see Harker, 1985). A major reason for this challenge is that many markets to which it has been applied, such as energy markets, steel markets, etc., are not reasonably perfectly competitive. Several authors have proposed new theoretical and mathematical models that allow for non-competitive markets (Harker, 1985; Hashimoto, 1985; Falk and McCormick, 1985).

CHAPTER III

THEORETICAL MODELS

III.1 Introduction

One of the objectives of this project is to determine the supply and demand for aggregate in a specific market. A spatial equilibrium model will be used to determine the trade flows between demand and supply regions. However, before these flows can be determined, we must be able to model what we call the "autarchy," or pre-trade, equilibrium. Before trade, there exists in each district "domestic" supply and demand and resulting autarchy equilibrium prices and quantities. These pre-trade equilibria represent the starting point for the trading activity. We will first develop the theoretical framework for determining domestic supply and demand at mine mouth[1]. The spatial equilibrium model will then be introduced to show how the estimated demand and supply by region can be used, together with transportation costs, to determine the price and quantities that reach a specific market.

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1 The mine-mouth is used as the site of the market since data include prices and quantities sold by producers on a mine location basis

III.2 The Autarchy Model

III.2.1 Demand

The demand side of this market is representable as an input demand derived from the production of buildings, highways and construction of other infrastructure. Let the production function for construction, broadly interpreted, be:

$$C_{it} = f(S_{it}, O_{it}) \qquad (1)$$

where C_{it} is the total construction activity in region i at time t; i.e., buildings, highway construction, etc, S_{it} is the total quantity of aggregate, and O_{it} is the total quantity of other inputs used in construction.

The derived input demand at mine mouth can be obtained by minimizing cost subject to the production function in (1):

$$\bar{s}_{it} = d(C_{it}, p_{it}, w_{it}) \qquad (2)$$

where p_{it} is the fob price of sand and gravel, w_{it} is the price of other inputs, and $\bar{s}_{it}$ is the input demand for aggregate.

Total construction activity reflects changes in stock and replacement of infrastructure. We will assume that the available information set[2] at time t consists of knowledge of past values of all the relevant variables that determine C_t, and that there exists a desirable level of

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[2] A detailed explanation on the role of information sets in forecasting can be found in Granger and Newbold, 1986

infrastructure, albeit unobservable, where actual infrastructure in place follows a partial adjustment model.

Let δ be depreciation of infrastructure stock and H_{it} the actual level of infrastructure in region i at time t. Then,

$$H_{it} = (1-\delta)\ H_{it-1} + C_{it} \qquad 0< \delta <1 \qquad (3)$$

where C_{it} is total construction activity. Let the desired level of infrastructure stock in i at time t, H^*_{it}, depend linearly on the population and per capita income in region i at time t:

$$H^*_{it} = \boldsymbol{\beta}(1\ pop_{i,t}\ pcinc_{i,t})', \qquad (4)$$

where $\boldsymbol{\beta}$ is a 3x1 parameter vector

Suppose that the adjustment of the actual infrastructure level, H_{it}, follows a proportional adjustment to H^*_{it}:

$$H_{it} - H_{i,t-1} = \gamma(H^*_{it} - H_{i,t-1}) + \epsilon_{it}; \quad 0< \gamma < 1 \qquad (5)$$

where γ is the proportion of adjustment and ϵ_{it} is an error term with mean zero and variance σ^2_ϵ. By successive substitution in (3) we obtain

$$H_{it} = (1-\delta)[(1-\delta)H_{i,t-2} + C_{i,t-1} + C_{i,t}]$$

$$\vdots$$

$$H_{it} = \Sigma^{\infty}_{j=0}\ (1-\delta)^j\ C_{i,t-j} \qquad (6)$$

By adding $\gamma H_{i,t-1}$ to both sides of (5) we obtain

$$H_{it} - (1-\gamma)H_{i,t-1} = \gamma H^*_{it} + \epsilon_{it} \qquad (7)$$

Substituting (6) and (4) into (7), and rearranging:

$$C_{it} = \gamma\beta_o + \gamma\beta_1 pop_{i,t} + \gamma\beta_2 pcinc_{i,t} + [(\delta-\gamma)/(1-\delta)]\Sigma_{j=1}^{\infty}(1-\delta)^j C_{i,t-j} + \epsilon_{it} \quad (8)$$

or

$$C_{it} = \pi_o + \pi_1 pop_{i,t} + \pi_2 pcinc_{i,t} + \pi_3 C_{i,t-1} + \pi_4 C_{i,t-2} + .. + \epsilon_{it} \quad (9)$$

The model proposed in (9) is a stochastic difference equation that would yield an optimal prediction for total construction demand at time t based on past information on construction activity, population, and income.

An alternative specification of (4) and (5) is that where the desired infrastructure level is taken to be a random variable. Under this alternative, an error term would be added in (4) instead of in (5). This specification can be found in Judge, et al. (1985). The consequences of choosing either alternative are discussed by Drymes (1971). By solving the resulting difference equations, (9) and its counterpart under the alternative specification, it is easily verified that the variance of the resulting error terms differs by a constant of proportionality.

Ideally, we would like to incorporate the dynamic nature of construction activity in the estimation of the input demand for aggregate, eq. (2). To do this, we would need a cross-section of time series that would incorporate dynamics in the cross-sectional estimation. Unfortunately, time series data for construction activity are only

available at an aggregated level higher than districts, making this option unfeasible. An alternative to this problem is the estimation of the time series model at a more aggregated level and the posterior use of the parameter estimates in the cross-sectional estimation. Preferences for types of construction can be assumed to be homogeneous across districts and states, without loss of generality. By making the assumption of homogeneous taste for construction type, the model in (9) can be estimated at the U.S. level for the purpose of this study. The goal is to capture the dynamics of construction activity and incorporate it into the cross sectional estimation of the demand for aggregates (2).

A second alternative would be to incorporate the variables believed to determine construction dynamics (i.e., past construction activity, population, and per capita income) directly into demand equation (2), for the cross-sectional estimation. This approach would, however, yield a completely static specification.

For the first option we would replace C_{it} in (2) by (9) yielding:

$$\bar{s}_i = d(\hat{c}_i, p_i, w_i) \qquad (10)$$

where, $\hat{c}_i = \hat{P}_o + \hat{P}_1 Pop_{i,t} + \hat{P}_2 Pcinc_{i,t} + \hat{P}_3 C_{i,t-1} + \hat{P}_4 C_{i,t-2} + \ldots$ This input demand can be estimated over a cross section of districts.

By assumption, ϵ_{it} in (9) is not autocorrelated. The number of lagged terms (i.e., the truncation lag) on C_{it} can be determined by testing $\hat{\epsilon}_{it}$ (OLS residuals) for autocorrelation. The presence of lagged dependent variables compromises the consistency of the OLS estimator only if ϵ_{it} is autocorrelated. It must be recognized that treating the parameter estimates from the time series model as known and constant across districts in the cross sectional estimation causes usual standard errors to overstate the efficiency of the estimation. This issue is further discussed in Section III.2.4 below. However, under general conditions, the cross-sectional estimator is consistent if the time series estimator is consistent.

The static specification would result in lagged values of construction activity, population, and per capita income being included in the set of explanatory variables in (2). The demand function would have the following general form:

$$\bar{s}_i = d(C_{i,t-1}, C_{i,t-2}, C_{i,t-3}, .., Pop_i, Pcinc_i, p_i, w_i) \qquad (11)$$

The functional form for the demand equation in (2), depends upon the assumed functional form of the production function in (1). Several alternatives, such as Cobb-Douglas and CES, are possible. Assuming the production function is a Cobb-Douglas, equation (2) would have the following functional form:

$$\bar{s}_i = (C_i)^{1/a} A^{1/a} (w_i b_1 / p_{it} b_2)^{b2/a} \qquad (12)$$

where $a=b_1 + b_2$ and A is a constant. The Cobb-Douglas

production function has been extensively used in the analysis of exhaustible resources. It is tractable to use. Kemp and Long (1980) have offered additional justification for its use in the context of exhaustible resources. Exhaustible resources as inputs of production will eventually go to zero. A general production function will approach the Cobb-Douglas form as the resource-input goes to zero.

The expression in (12) can be log-linearized:

$$\ln(\tilde{s}_{id}) = \alpha_{01} + \alpha_{11}\ln(C_i) + \alpha_{21}\ln(w_i) + \Phi_{11}\ln(p_i) \quad (13)$$

where $\Phi_{11} < 0$, is the price elasticity of the input demand, α_{11} is the elasticity of construction activity, and α_{21} is the elasticity of other production inputs.

If the alternative presented in (10) is used, then the model for the mine-mouth demand is:

$$\ln(\tilde{s}_{id}) = \alpha_{01} + \alpha_{11}\ln(\hat{c}_i) + \alpha_{21}\ln(w_i) + \Phi_{11}\ln(p_i) + \mu_{1i} \quad (14)$$

On the other hand, using the alternative represented by (11) the demand equation is:

$$\ln(\tilde{s}_{id}) = \alpha_{01} + \alpha_{11}\ln(C_{i,t-1}) + \alpha_{21}\ln(Pop_i) + \alpha_{31}\ln(Pcinc_i) + \alpha_{41}\ln(w_i) + \Phi_{11}\ln(p_i) + e_{1i} \quad (15)$$

III.2.2 Supply

The supply of aggregates to a particular market will crucially depend on transportation costs. However at mine mouth, the determinants would be the fob price, the costs of production, and availability of inventories. Costs of

production are difficult to obtain, since producers are reluctant to give out what is considered confidential information and supply conditions vary geographically. Sand and gravel pits and crushed stone quarries often coexist in the same area[3]. The equipment needed for some of the processes is similar (washing, screening, grading, and transportation equipment). Moreover, many companies own both sand and gravel pits and stone quarries. This degree of rivalry in the use of the same inputs of production between sand and gravel and crushed stone can be exploited for modeling purposes.

Output prices can, under certain assumptions, be expressed as functions of input prices. Jorgenson and Fraumeni (1981) denote this function as the sectoral price function. Therefore, output price is a reflection of inputs use and substitution. This has been utilized several times in natural resources by modeling quantity supplied of a given product as a function of the ratio of output prices, the own price to the price of the other output which is rival in the use of factors of production. By this argument, we expect that changes in the price of stone will shift the supply of sand and gravel, and vice versa. We must, however, recognize that stone has substitutability with gravel in some uses. The substitutability mainly

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[3] Coexistence of both activities has been documented by the Committee on Surface Mining and Reclamation (1980).

occurs in asphaltic concrete, where angular or flattish fragments do not compromise stability. However, concrete aggregate, used for residential and nonresidential construction, requires naturally round particles to insure strength, making crushed stone undesirable for these uses (Evans, 1978).

The supply function proposed for the estimation of the autarchy system is a very simple one. Let $q_{i,t-1}$ be the price of crushed stone in district i at time t-1, then

$$\bar{s}_{is} = s(p_i/q_{i,t-1}) \qquad (16)$$

that is, the supply of aggregates is a function of the output price ratio between sand and gravel, and crushed stone. The expression in (16) can be expressed in log-linear form:

$$\ln(\bar{s}_{is}) = \alpha_{o2} + \alpha_{12}\ln(q_{i,t-1}) + \Phi_{12}\ln(p_i) + \mu_{2i} \qquad (17)$$

where $\Phi_{12} > 0$, is the own price elasticity of supply.

III.2.3 The Econometric (Statistical) Model of the Autarchy Equilibrium

The two alternative specifications for the market equilibrium before trade are:

Statistical Model 1

$$\ln(\bar{s}_{id}) = \alpha_{o1} + \alpha_{11}\ln(\hat{c}_i) + \alpha_{21}\ln(w_i) + \Phi_{11}\ln(p_i) + \mu_{1i}$$

$$\ln(\bar{s}_{is}) = \alpha_{o2} + \alpha_{12}\ln(q_{i,t-1}) + \Phi_{12}\ln(p_i) + \mu_{2i} \qquad (18)$$

$$\ln(\bar{s}_{id}) = \ln(\bar{s}_{is})$$

Statistical Model 2

$$\ln(\bar{s}_{id}) = \alpha_{01} + \alpha_{11}\ln(C_{i,t-1}) + \alpha_{21}\ln(Pop_i) + \alpha_{31}\ln(Pcinc_i) + \alpha_{41}\ln(w_i) + \Phi_{11}\ln(p_i) + e_{1i}$$

$$\ln(\bar{s}_{is}) = \alpha_{02} + \alpha_{12}\ln(q_{i,t-1}) + \Phi_{12}\ln(p_i) + e_{2i} \qquad (19)$$

$$\ln(\bar{s}_{id}) = \ln(\bar{s}_{is})$$

Where in both cases an error term has been added to the log-linear supply model. The error terms are assumed independent and identically distributed.

The estimation of the structural parameters of these linear two-equation systems can be carried out using either a system estimator or a single equation estimator, if the system is identified. We will first discuss identification of the statistical models presented above, and then briefly address the issue of alternative estimators.

Identification of structural parameters in a simultaneous equations system is a matter of concern for estimation purposes. Two conditions must be satisfied for identification. A necessary and sufficient condition for identification is the "rank condition." A necessary condition for identification is the "order condition." When using <u>a priori</u> exclusion restrictions, the order condition requires that the number of excluded variables in the ith equation be greater than or equal to M-1, where M is the number of endogenous variables in the system. The rank condition requires that the excluded variables in the ith equation appear in the remaining equations (M-1). For our

case the rank condition implies that variables excluded in the demand equation must appear in the supply equation and vice versa[4].

The discussion of the identification of Statistical Model 1 is postponed to Section III.2.4.

In Statistical Model 2 the following applies for the demand equation:

a) the number of excluded variables in the demand equation is 1 (M-1=1) and therefore the order condition is satisfied,

b) the exogenous variable excluded from the demand equation ($\ln(q_{i,t-1})$) appears in the supply equation, and therefore, the rank condition is satisfied.

By a) and b) the demand equation is just identified.

For the supply equation:

a') the number of excluded variables in the supply equation is 4 (4 > M-1=1) therefore the order condition is satisfied,

b') the exogenous variables excluded from the supply equation ($\ln(w_{it})$, $\ln(C_{i,t-1})$, $\ln(Pop_{it})$, and $\ln(Pcinc_{it})$) appear in the demand equation and therefore the rank condition is satisfied.

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[4] The reader is referred to Judge et al.(1985) for the conditions required for identification of linear simultaneous equations models.

By a') and b') the supply equation is overidentified.

Estimation of a system of equations can be carried out by system estimators or single equation estimators. The system estimators can improve the efficiency of the estimation in a correctly specified model. However, even though system estimators are asymptotically more efficient, any specification error in the structure of the model will be propagated throughout the system by 3SLS or FIML (see Greene, 1990 pages 636-638, for a detailed discussion). In our particular case, the short-run supply function for a non-renewable resource would depend upon mining costs and the ratio of inventories to production. The limitations of data may lead to misspecification of the supply equation because of these omitted variables. A system estimation is most likely to propagate the misspecification to the estimation of demand. For this reason, we will estimate the two alternative Statistical Models by 2SLS.

III.2.4 A Digression on Latent (Unobservable) Variables

Many economic applications depend on the use of observable proxies for otherwise unobservable conceptual variables. Moreover, economic quantities are frequently measured with error. In Section III.2.1 a two step estimation procedure for the demand side of the aggregates markets was presented. This section is mainly designed to show the direct relationship between the latent variables

literature and our specific problem.

Within the context of a single equation model, a typical error of measurement in the independent variables would be presented as follows:

$$\mathbf{y} = \zeta\beta + \epsilon; \qquad E(\epsilon\epsilon') = \sigma^2 I_N \tag{20}$$

$$\mathbf{x} = \zeta + \upsilon; \qquad E(\upsilon\upsilon') = \sigma^2_{\iota\iota} I_N \tag{21}$$

$$E(\zeta\zeta') = \sigma^2_{ff} I_N$$

ζ, ϵ, υ are unobservable. Consistent estimation can only be obtained by additional information since as it stands the parameters of this model are not identified. Let W be a matrix of observable variables, then

$$\zeta = W\alpha + \mu \tag{23}$$

The variables in W are considered <u>causes</u> of ζ apart from a random error term.

Additional information in the form of an extra indicator being available for an unobservable variable is the most frequently considered cure for the errors-in-variables, latent variable, identification problem (Aigner et al., 1987).

In (20), **y** can be interpreted as an <u>indicator</u> of ζ. The model in (20), (21), and (23) is then known as the Multiple Indicator-Multiple Cause (MIMIC) model relating a single unobservable to a number of indicators and a number of exogenous variables. The MIMIC model was introduced to the econometrics literature by Goldberger (1972). By eliminating ζ it can be shown that all the parameters are

identified (Aigner et al., 1987). However in (20) and (21), no simultaneity is involved.

The problem becomes more cumbersome when we move to simultaneous equations models. It is clear that simultaneity can, in some cases, contribute to solving the problem of identification when variables are measured with error. A simple example is that of a two equations system where one equation is overidentified and the other is just-identified if all exogenous variables are measured without error. Suppose instead that one exogenous variable in the system is measured with error. If that variable appears in the equation that was originally overidentified. Then, the overidentifying restriction can be used to consistently estimate the extra parameter (i.e., the variance of the measurement error)[5]. However, an exogenous variable measured with error appearing in the equation that was otherwise just-identified, makes the equation underidentified. Similar versions of this example can be found in Goldberger (1974) and Aigner et al (1987).

Before moving to the use of additional information in simultaneous equations model, we will briefly discuss the identification of Statistical Model 1 from Section III.2.3. The prediction for C_i developed in Section III.2.1, can be viewed as the development of a proxy for an unobservable

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[5] For a detailed discussion see Goldberger (1974) pages 207-211 or Aigner et al.(1987) pages 1363-1369.

variable. Note that the input demand equation was originally,

$$\ln(\bar{s}_{id}) = \alpha_{o1} + \alpha_{11}\ln(C_i) + \alpha_{21}\ln(w_i) + \Phi_{11}\ln(p_i) \quad (13)$$

where $C_i = \hat{c}_i + v$, and the analogy to equations (20) and (21) is clear. Within the context of Statistical Model 1, the demand equation would be just-identified if C_i were measured without error. It then follows by the previous discussion, that unless additional information is used, the demand equation in Statistical Model 1 is underidentified.

Jöreskog-Keesling-Wiley approach to the latent variables problem, popularized by LISREL[6], uses additional information in the context of simultaneous equations models. The model chosen to relate the unmeasured or latent variables that might acutally be measured was the factor-analytic model. Let y and x be observable variables, η and ζ be the unobservable endogenous and exogenous variables in the simultaneous equations system respectively, then,

$$y = \Lambda_y\eta + \epsilon \quad \text{and} \quad x = \Lambda_x\zeta + \delta \qquad (24)$$

is the measurement model imposed on the variables involved in the simultaneous equations system. Λ_y and Λ_x are the so-called factor loading matrices of the structural regression of measured on unmeasured variables (using LISREL notation). This model is not designed to deal with structural relations

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[6] LISREL is the copyrighted name of a computer program

where the variables related in the system of equations are first-order factors or measured variables (Bentler, 1983).

Bentler (1983) presents an alternative approach, namely moment structure models. The framework is a mixture of traditional econometrics and psychometrics where the simultaneous equations model does not need additional structure to handle latent variables.

Even though we will not pursue the estimation of Statistical Model 1 with MIMIC models, the purpose of this section was to note that our theoretical construct could be placed within this framework and suggest that it is a fruitful area for further research.

III.3 Spatial Equilibrium Analysis

In principle, the aggregate markets can result in flows of exports and imports between districts depending upon demand and supply conditions in each district market, and upon transportation costs. Studying aggregate markets implies a problem of predicting interregional commodity movements and regional prices among spatially separated markets. Enke (1951) first formulated the problem concerning equilibrium among spatially separated markets. Samuelson (1952) formalized Enke's formulation as a nonlinear optimization problem, and Takayama and Judge (1964) derived the quadratic programming representation.

Samuelson's concept is illustrated in Figure III.1, Market 1 is an export market to Market 2. Shipments from Market 1 to Market 2 will increase to an equilibrium level at B where exports of 1 (ES_1) match imports of 2 (ES_2) at the differential between p_2 and p_1 equal to transport costs, $T_{1,2}$. Samuelson (1952) defined the concept of social pay-off associated with this problem. Let ES_i, i=1,2 be the excess-supply function in market i, which is equal to the demand curve subtracted laterally at every price from the supply curve. The ES_i curves are shown in Figure III.2. Let $T_{12}=t_{21}$ be the transport cost between markets 1 and 2, denoted by WXOYFZ, and let NN be the vertical difference between the two excess supply curves in Figure III.2.

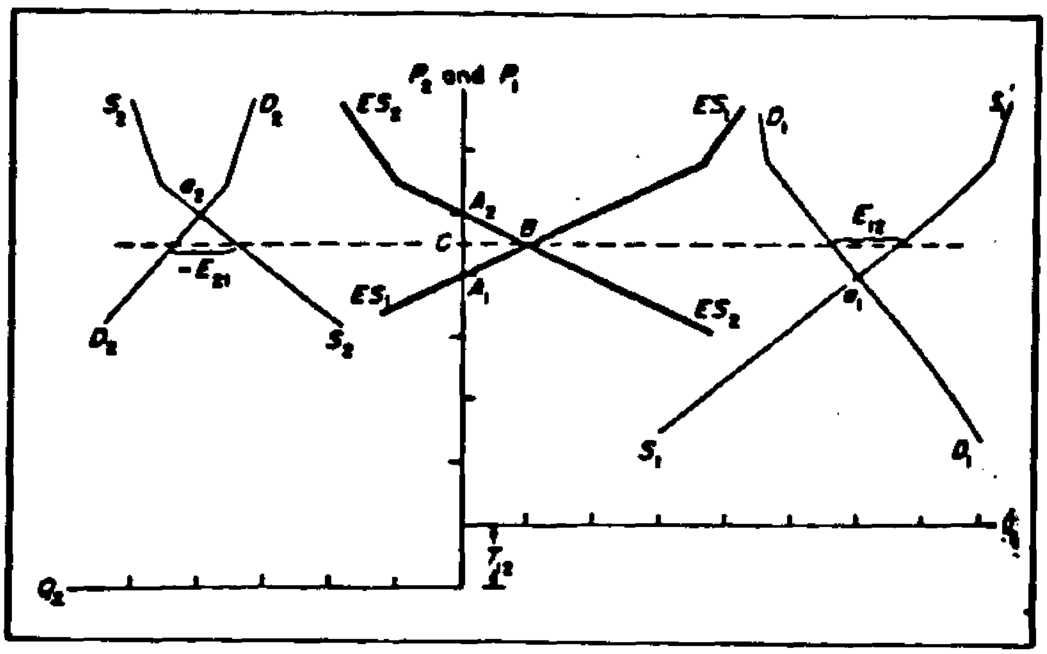

Figure III.1. **Equilibrium of Exports and Imports**

Source: Samuelson, 1952

The area A_1JKA_2 is equivalent to OMFG,

> "OMFG,..,cries out to be compared with the area under the transport curve, OMFY. However, the name consumers surplus has all kinds of strange connotations in economics. To avoid these and to underline the completely artificial nature of my procedure, I shall simply define a "net social pay-off" (Samuelson,1952)."

Samuelson proceeded to define social pay-off for any region as the algebraic area under its excess-demand curve, which is equal in magnitude to the area under its excess-supply curve but opposite in algebraic sign. In Figure III.2, having put market 1 and market 2 back-to-back and subtracted the area under the first market's excess-supply curve from the second market's (i.e., NN curve) implies that NN measures the combined social pay-off of both markets. In Figure III.3 NON indicates the combined payoff of the two markets when exports from 1 to 2 vary. Subtracting transportation costs (curve UOU) from combined pay-off (curve NON) we obtain the net social pay-off curve, NSP. Thus, for all regions the NSP is the sum of the n separate payoffs minus the total transport costs of all shipments.

Takayama and Judge (1964) proposed a quadratic programming solution to the spatial equilibrium models of the Enke-Samuelson variety. They considered solutions for: (1) linear regional demand functions and fixed regional supplies; (2) fixed regional demands and linear regional supply functions; and , (3) multiproduct linear regional

demand and supply functions with linear substitution and/or complementary terms admitted.

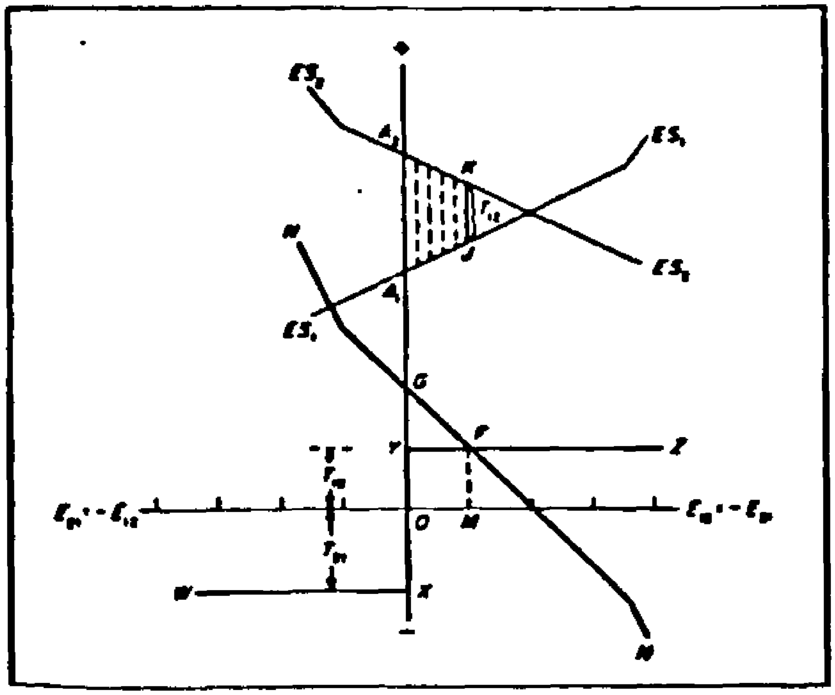

Figure III.2. **Spatial Equilibrium**

Source: Samuelson, 1952

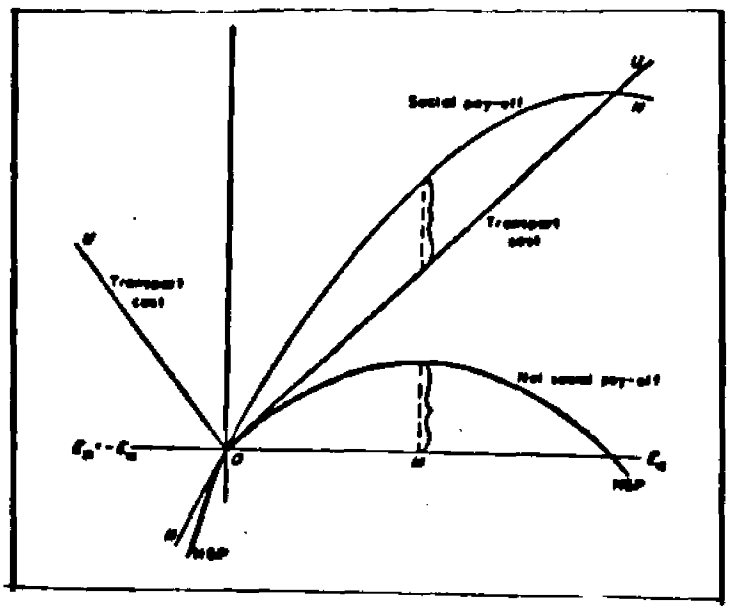

Figure III.3. Net Social Pay-off

Source: Samuelson, 1952

For simplicity of exposition, Takayama and Judge's original notation will be used throughout the remainder of this section.

Assume there are n regions with specified linear regional demand and supply relations, denoted:

$$d_i = \alpha_i - \beta_i p_i;\ \alpha_i, \beta_i > 0 \text{ for } i=1,2,\ldots,n$$

(21)

$$s_i = h_i + \gamma_i p_i;\ h_i \le \text{ or } \ge 0,\ \gamma_i > 0 \quad \text{for } i=1,2,\ldots,n$$

let t_{ij} be the transport cost per unit between the ith and jth regions and x_{ij} the nonnegative flow activities between the supply and demand points.

Maximizing Samuelson's NSP can be written in a programming formulation as follows:

$$\max F(X) = \Sigma_i \lambda_i \Sigma_i x_{ij} - ½ \Sigma_i \omega_i (\Sigma_j x_{ij})^2 - \Sigma_j \mu_j \Sigma_i x_{ij}$$

$$- ½ \Sigma_j \eta_j (\Sigma_i x_{ij})^2$$

subject to:

$$\lambda_i - \omega_i(\Sigma_j x_{ij}) - \mu_j - \eta_j(\Sigma_i x_{ij}) \le tij$$

and

$$x_{ij} \ge 0 \text{ and } \partial f(X)/\partial x_{ij} = 0$$

where

$\lambda_i = \alpha_i/\beta_i$, $\omega_i = 1/\beta_i$, $\mu_j = -h_i/\gamma_i$, $\eta_j = 1/\gamma_i$ for $i,j=1,2,\ldots,n$

The operationally feasible specification is obtained by converting the domain from x to p, in matrix notation:

$$\max f(P) = \begin{pmatrix} \alpha \\ -h \end{pmatrix}' P - P' \begin{pmatrix} \beta & 0 \\ 0 & \gamma \end{pmatrix} P$$

subject to

$p_i - p^j \leq t_{ij},\ p_i,\ p^j \geq 0,$

where $(p_d,\ p^s)$ denotes prices at the i, j demand and supply points, and $P = (p_1, p_2, \ldots., p_n, p^1, p^2, \ldots., p^n)'$

The solution to this problem will jointly determine import and export flows and market clearing delivered prices for all included market areas. These prices can be compared to pre-trade, autarchy prices.

CHAPTER IV

MODEL ESTIMATION

IV.1 Introduction

In principle, to develop a trade model, autarchic supply and demand must be estimated. In our case, this means domestic supply and demand, where domestic means each district. Observing producer sales at mine-mouth provides domestic supply information, by definition. However, these data reflect domestic (within district) plus export (to other districts) demand. Therefore, the demand curve estimated with mine-mouth data is the total fob demand, i.e., sum of domestic and export demand. This is a minor problem if there is no trade. If transport costs are so high that little trade has occurred historically, there is no problem. This is likely to be the case, and we will explore these issues in Chapter VI. The present chapter presents the estimation of the Statistical Models introduced in Chapter III.

IV.2. The Autarchy Model Results

IV.2.1. A Time Series Model for Construction Activity

The partial adjustment model for construction activity developed in Chapter III yielded the following reduced form dynamic specification:

$$C_t = \pi_0 + \pi_1 pop_t + \pi_2 pcinc_t + \pi_3 C_{t-1} + \pi_4 C_{t-2} + \ldots + \epsilon_t \quad (9)$$

where C_t is the real value of construction; pop_t is population; and $pcinc_t$ is real per capita income. By definition, ϵ_t is a zero-mean white noise process.

The estimates of π obtained from model (9), are to be introduced into the estimation of the demand in the cross-sectional simultaneous equation model established in section IV.2.2. Since the data for the cross-sectional estimation are annual, estimation of (9) must be undertaken with the _same_ series available at county level and on an annual basis. The _County and City Data Book_, 1988, published the value of residential construction, nonresidential construction, and residential and nonresidential additions and alterations by permit issuing places for 1986. County level construction data were not published in numbers of buildings, but in dollars values. Therefore, the estimation at the U.S. level can only be conducted using the real dollar value of construction. Annual data on the values of residential construction, nonresidential construction, and addition and alterations by permit issuing places are published by _Construction Report_ (U.S. Department of Commerce, varying years) at the U.S. level. A price deflator for the construction industry, is available from _Citibase_ (Citicorp Economic Database). Annual data on population and per capita income for the U.S. were also available from _Citibase_ (Citicorp Economic Database).

Before addressing the estimation of (9), we must test the stationary[1] properties of each one of the series; i.e., real value of construction, population, and per capita income. The issue of whether the series are individually stationary is an important one. Regressing a stationary series on a non-stationary series, or vice versa, has serious consequences known as "Spurious Regression" or "Non-sense Regression" in the time series econometrics literature (Granger and Newbold, 1986; Hendry, 1992). If one or more of the series in the model were non-stationary, the assumptions of the classical linear model would not hold[2].

Testing for the non-stationarity of individual series reduces to testing whether $\alpha=1$ in $Y_t = \alpha Y_{t-1} + u_t$, where Y_t is an individual data series; e.g. construction, population, or per capita income. This testing procedure is known as "Testing for the Presence of a Unit Root." The distribution of the "student-t" statistics does not have a standard distribution under this null hypothesis[3]. However, critical values for this non-standard distribution were tabulated by Dickey using Monte Carlo methods and were given in Table

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1 For a formal definition of stationary processes the reader is referred to Granger and Newbold (1986).

2 The convergence of $X'X/T$ to a finite matrix is violated.

3 The convergence to the limiting distribution is much faster than that of a stationary series. The intuition is that the denominator of the "t-statistics" does not hover around a constant level.

8.5.2 of Fuller (1976). The assumptions of the Dickey-Fuller test are that u_t is a zero-mean white noise process. The reader is referred to Harvey (1991) for a more detailed explanation of the Dickey-Fuller unit root test. If u_t is not white noise, differenced lagged terms are added and the test is called Augmented Dickey-Fuller.

The unit root tests can be represented as follows:

a) Dickey-Fuller

Regression (i): $Y_t = \mu^* + \alpha^* Y_{t-1} + u_t$

Test: $t\alpha^*$ (Ho:α=1),Φ_1 (Ho:α=1, μ=0)

Regression (ii): $Y_t = \tilde{M} + \tilde{B}t + \tilde{A}Y_{t-1} + \tilde{u}_t$

Test:$t\tilde{\alpha}$ (Ho:α=1), Φ_2 (Ho:α=1, μ=0, β=0),Φ_3 (Ho:α=1, β=0)

b) Augmented Dickey-Fuller

Regression (i): $Y_t = \mu^* + \alpha^* Y_{t-1} + \Sigma_{j=1}^{p} \alpha_j \Delta Y_{t-j} + u_t$

Test: $t\alpha^*$ (Ho:α=1),Φ_1 (Ho:α=1, μ=0)

Regression (ii): $Y_t = \tilde{M} + \tilde{B}t + \tilde{A}Y_{t-1} + \Sigma_{j=1}^{p} \alpha_j \Delta Y_{t-j} + \tilde{u}_t$

Test:$t\tilde{\alpha}$ (Ho:α=1), Φ_2 (Ho:α=1, μ=0, β=0),Φ_3 (Ho:α=1, β=0)

Dickey-Fuller and Augmented Dickey-Fuller test statistics were calculated for each of the series in model (9). The optimum augmentation lag was calculated using AIC and SIC criteria[4]. A sample of 31 years (1959-1989) was available for the estimation of model (9). This is a small sample and it must be recognized that the power of the unit root tests is affected by sample size. The Department of Commerce

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[4] AIC = $\ln \hat{r}^2 + 2(p)/T$; SIC = $\ln \hat{r}^2 + (\ln T)(p)/T$
where p is the number of autoregressive terms

series, "Value of Construction by Permits," was only available since 1959[5]. Table IV.1 presents the results for the Dickey-Fuller and Augmented Dickey-Fuller "t-statistics" and "F-statistics" versions of the unit root tests[6].

Perron (1988) proposed a testing strategy to choose between regressions (i) and (ii) above. Since the statistics from model (i) cannot distinguish a stationary process around a linear trend from a process with a unit root, analysis should always start from model (ii). If the value of Φ_3 leads to rejection of the null, and so does the value of tÃ, we conclude that the series is stationary around a linear trend. That is the case of two of the series in Table IV.1: Real Value of Construction by Permits and Population. In both cases the values are larger than the 5% critical value (tÃ=-4.876 and Φ_3=11.916 for construction permits series; tÃ= -3.967 and Φ_3= 7.944 for the population series). Instead, if tÃ and Φ_3 fail to reject the null and Φ_2 rejects the null, we proceed to model (i). For the per capita income series, Φ_3=3.742, tÃ=-2.476, and Φ_2=46.271, therefore, we move to statistics from model (i). If Φ_1 rejects the null and t_{a}. fails to reject, then we

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[5] The series is available on a monthly basis; however, that is not suitable for the purpose of this empirical application

[6] The reader is referred to Perron (1988) for a summary of all available statistics

conclude that the series is integrated i.e., non-stationary. The value of t_{a^*} is 0.909 larger than the critical value; and therefore, we fail to reject the null hypothesis of $\alpha = 1$.

Table IV.1

Dickey-Fuller and

Augmented Dickey-Fuller Unit Root Test

	Test	Critical Value (5%)**
Construction Permits (Augmentation lag=1*)		
t_{a^*}	-2.435	-3.00
Φ_1	3.245	5.18
tÃ	-4.876	-3.60
Φ_2	8.228	5.68
Φ_3	11.916	7.24
Population (Augmentation lag=1*)		
t_{a^*}	0.223	-3.00
Φ_1	2.409	5.18
tÃ	-3.967	-3.60
Φ_2	7.792	5.68
Φ_3	7.944	7.24
Per Capita Income (Dickey-Fuller=0*)		
t_{a^*}	0.909	-3.00
Φ_1	55.304	5.18
tÃ	-2.476	-3.60
Φ_2	46.271	5.68
Φ_3	3.742	7.24

* Determined by AIC and SIC
** Critical Values are from Fuller, 1976 pp. 373 and Dickey and Fuller, 1981 pp 1063.

The results imply that one the explanatory variables, per capita income, is non-stationary violating the assumptions of the classical linear model. Estimation of (9) is then carried out with Real Value of Construction Permits and Population in levels, and Real Per Capita Income

in first differences. The OLS estimation of model (9) for the U.S. yielded (probability values in parenthesis):

$$C_{1t} = \underset{(.004)}{-78755} + \underset{(.0005)}{0.6595pop_t} + \underset{(.0000)}{20.592\Delta pcinc} + \underset{(.0033)}{0.36756C_{t-1}} \quad (23)$$

$$R^2 = 0.8697, \ T=29$$

Durbin H Statistic = 0.49537 (asymptotic normal)

$Q_{(12)} = 10.81 \ (\chi^2_{(\alpha=5\%)} = 21.026)$

$Q_{(24)} = 21.33 \ (\chi^2_{(\alpha=5\%)} = 36.415)$

The estimation in (23) indicates that population, changes in per capita income and lagged real construction values are all positively correlated with real value of construction. Durbin H statistics and Box-Pierce-Ljung Portmanteau Q-statistics indicate that $\hat{\epsilon}_t$ is not serially correlated. This later results is important since the OLS estimator is inconsistent if a lagged dependent variable model has autocorrelated errors (See Judge et al., 1985, Ch. 5).

IV.2.2 A Simultaneous Equation Model of Sand, Gravel and Crushed Stone Markets

Two alternative models were presented in Chapter III. Statistical model 1 incorporated the parameter estimates from model (9) in predicting construction activity, and Statistical Model 2 incorporated population, per capita income, and value of construction directly as explanatory variables in the demand equation. These models are reproduced below:

Statistical Model 1

$$\ln(\tilde{s}_{id}) = \alpha_{o1} + \alpha_{11}\ln(\hat{c}_i) + \alpha_{21}\ln(w_i) + \Phi_{11}\ln(p_i) + \mu_{1i}$$

$$\ln(\tilde{s}_{is}) = \alpha_{o2} + \alpha_{12}\ln(q_{i,t-1}) + \Phi_{12}\ln(p_i) + \mu_{2i} \qquad (18)$$

where $\hat{c}_i = \hat{P}_o + \hat{P}_1 Pop_i + \hat{P}_2 Pcinc_i + \hat{P}_3 C_{i,t-1}$

Statistical Model 2

$$\ln(\tilde{s}_{id}) = \alpha_{o1} + \alpha_{11}\ln(C_{i,t-1}) + \alpha_{21}\ln(Pop_i) + \alpha_{31}\ln(Pcinc_i) + \alpha_{41}\ln(w_i) + \Phi_{11}\ln(p_i) + e_{1i}$$

$$\ln(\tilde{s}_{is}) = \alpha_{o2} + \alpha_{12}\ln(q_{i,t-1}) + \Phi_{12}\ln(p_i) + e_{2i} \qquad (19)$$

Simultaneous determination of prices and quantities implies that in equilibrium $\ln(\tilde{s}_{id}) = \ln(\tilde{s}_{is})$. Both specifications were estimated using 2SLS (see chapter III for discussion on alternative estimators).

Data for Value of Construction by Permits were obtained from the City-County Data Book, 1988. Average construction workers wages, population, and per capita income at the county level were obtained from the Regional Economic Information System for the period 1982-1989 (REIS). Sand, gravel, and crushed stone data at district levels were obtained from the Bureau of Mines, Crushed Stone and Sand and Gravel Production by State Districts. 1985-1986 and Minerals Yearbook, Vol.II, Area Reports for 1987 and 1988. Sand and gravel data have been published at the district level for 1986 and 1988 and crushed stone data have been published at this level for 1985, 1987, and 1989. The published information contained total quantity (in thousands of short tons) and total value (in thousands of dollars)

sold by district for construction purposes of sand and gravel jointly, and crushed stone separately. The Bureau designated an average of 4 districts in each one of 40 states of the U.S. by grouping adjacent counties. Using Fips county codes, we mapped the county level data (over 3000 observations) into districts. Fips coding is a numbering system whereby each state of the U.S. is represented by a two digit number, and each county within each state can be identified by a three digit number. The REIS and County and City Data Book data are coded by Fips codes. The complete district level data set contained a total of 165 districts in 40 states. Whenever a particular district had less than 3 operations the Bureau did not publish the information to protect particular operations. Therefore, in many districts we had missing values. The simultaneous equations models, (18) and (19), were estimated for the cross-section of districts for 40 states in the U.S. Results are presented in Tables IV.2 and IV.4 with probability values in parenthesis. The data on quantity sold and the total value of shipments were used to calculate p_i, fob price, using the ratio, value/quantity. The variable $q_{i,t-1}$ in Table IV.2 represents the lagged price of crushed stone in district i. Finally, w_i is the average construction worker wage, calculated as the ratio of total construction worker's earnings to the total number of hours worked (REIS).

The variable, Value of Construction by Permits, contains information on residential and nonresidential construction, as well as total additions and alterations. However, this variable does not contain information on highway construction. Permit data are collected at county levels, and highway projects are reported at state levels. For this reason we will present two sets of estimates of the sand and gravel systems. The first set of estimates labelled "Building Construction," includes only sand and gravel used for building construction. This was calculated by subtracting the quantity of sand and gravel sold for asphaltic concrete aggregate, snow and ice control, railroad ballast and road fill uses from the total quantity of sand and gravel sold. This is shown in column 1 of Table IV.2. The second labelled "All Construction," and includes the total construction sand and gravel sold by district (column 2 of Table IV.2), this includes concrete aggregate, asphaltic concrete aggregate, fill, snow and ice control, railroad ballast, roofing miscellaneous, other.

The demand equations were derived as input demands from a Cobb-Douglas production function (see Chapter III for the theoretical considerations). The price elasticity of the competing input in construction production, labor, is expected to be positively related to the quantity of aggregate demanded (Beattie and Taylor, 1985). Parameter estimates for w_i in Table VI.2 were positive and significant

for both "Building Construction" and "All Construction," equations. The variable $\hat{c}_i$ is the measure of total output

Table IV.2

2SLS Estimates of Supply and Demand for Sand and Gravel, using Statistical Model 1 (probability values in parenthesis)

DEMAND:	Building Construct.	All Construction
Intercept	-1.0168	-2.1015
	(.573)	(0.268)
$\ln(\hat{c}_i)$	0.3557	0.2183
	(.0001)	(0.0035)
$\ln(p_i)$	-1.3209	-0.7988
	(0.270)	(0.6357)
$\ln(w_i)$	1.7505	2.6169
	(0.019)	(0.018)
SUPPLY:		
Intercept	-0.8076	-2.2706
	(0.843)	(0.702)
$\ln(p_i)$	8.3369	10.8066
	(0.040)	(0.082)
$\ln(q_{i,t-1})$	-2.1653	-1.9487
	(0.091)	(0.187)
N	100	96

in the input demand equation[7]. This parameter estimate is expected to be positive. The estimates are 0.3557 for "Building Construction" and 0.2183 for "All Construction" and both are significant at the 1% level. The own price elasticity of demand is naturally expected to be negative. Parameter estimates were -1.3209 and -0.7988 for the estimated demands in Table IV.2. In both cases however, the estimates were not significant as indicated by the probability values. Our expectations were that demands for

[7] Since the demand was derived from a Cobb-Douglas type production function from construction.

aggregates were price inelastic. This was based on the relatively low cost share of construction aggregates in the total cost of construction.

On the supply side, the theoretical model suggested that quantity supply was a function of the ratio of the own price to the lagged competing output price. By estimating this relationship as linear in logarithms, it was expected that the estimate of the coefficient for the lagged price of the competing output would be negative. The parameter estimates for the lagged price of crushed stone parameter estimates were -2.1653 and -1.9487 in the sand and gravel equations in Table VI.2, using "Building Construction" and "All construction," respectively. The p-values were 0.091 and 0.187, respectively. The estimates of the supply own price elasticity were 8.3369 for "Building construction" and 10.8066 for "All construction" uses, with p-values 0.040 and 0.082 respectively.

The model was estimated from a cross-section of districts. When demand varies across districts, supply is adjusting to this variation in demand. The supply is therefore the result of long-term decisions regarding the whole process of exploration and development of the mineral resources. Since we were not able to control for potential fixed factors, such as capital and land in production, the estimated supply is a reflection of long run equilibria

across districts. Short-run supply elasticity is likely to be less elastic than the estimates in Table IV.2.

The assumption of a nearly perfectly elastic supply has allowed researchers to simplified estimation of demand since under that condition the demand function is estimable by OLS (Balestra and Nerlove, 1966; Toweh and Newcomb, 1991). Although ordinary least squares is a biased estimator of the structural parameters of a simultaneous equations model, in practice estimates, in some cases, have been found surprisingly close to those of the structural estimator. This must however be tempered by the finding that the OLS standard errors are, in all likelihood, not useful for inference purposes (see Greene (1990) for a discussion). For comparison purposes the OLS estimates of the demand equations are shown in Table IV.3

Table IV.3

OLS Estimates of Demand for
Sand and Gravel
(probability values in parenthesis)

	Building Construct.	All Construction
Intercept	-0.975	-2.455
	(0.579)	(0.188)
$\ln(\hat{c}_i)$	0.394	0.225
	(0.0001)	(0.002)
$\ln(p_i)$	-1.390	-0.355
	(0.0001)	(0.299)
$\ln(w_i)$	1.604	2.515
	(0.013)	(0.0003)
R^2	0.425	0.301
N	100	104

The OLS estimates of the demand parameters are very close to the 2SLS estimates, reported in Table IV.2, for the case of "Building Construction." The OLS estimates of "All Construction" sand and gravel demand are also close except for the coefficient of price of sand and gravel. In both cases, 2SLS an OLS, "Building Construction" demand appears to be price elastic while "All Construction" demand appears to be price inelastic.

Table IV.4 presents the estimated 2SLS values of demand and supply for crushed stone and the OLS estimates of demand for crushed stone. The lagged price of sand and gravel used in the estimation of crushed stone supply, $p_{i,t-1}$ is the price of total sand and gravel sold for all construction purposes.

Table IV.4

2SLS Estimates of Supply and Demand and OLS estimates of Demand for Crushed Stone, using Statistical Model 1 (probability values in parenthesis)

DEMAND:	2SLS	OLS
Intercept	7.7585	7.015
	(0.011)	(0.0001)
$\ln(\hat{c}_i)$	0.4360	0.445
	(0.0001)	(0.0001)
$\ln(q_i)$	-0.8534	-0.295
	(0.4405)	(0.178)
$\ln(w_i)$	-1.0104	-1.060
	(0.165)	(0.073)
R^2		0.359
SUPPLY		
Intercept	6.04924	
	(0.0224)	
$\ln(q_i)$	2.3263	
	(0.312)	
$\ln(p_{i,t-1})$	-0.5858	
	(0.487)	
N	89	95

The parameter estimate of construction wages in the demand equation was negative but insignificant in both cases 2SLS and OLS. This sign was expected positive since the demand equation is derived from a Cobb-Douglas production function. The 2SLS estimate of the coefficient for $\ln(\hat{c}_i)$ is 0.4360 and it is significant at 1%. The 2SLS estimated price elasticity of demand is -0.8534, which was not significant. The estimate for the lagged sand and gravel price parameter in the supply function is -0.5858 with a p-value of 0.487. The estimate of the own price elasticity of supply for crushed stone is 2.3263 (p-value= 0.312). The OLS estimates of the demand parameters are close to those of 2SLS except for the coefficient of the price of crushed stone.

Estimation of Statistical Model 2, equations (19), yielded insignificant estimates for most coefficients. Demand elasticities were opposite in sign to expectations in most cases. This specification is static (see (19) above). Balestra and Nerlove (1966) found the same type of results when estimating the demand for natural gas. They argued that the empirical arguments supported the dynamic specification, and our findings seem to indicate that the same results hold for aggregate markets.

IV.3 Summary of Findings

Construction activity is found to be related to lagged values of construction activity, population, and changes in

income. Only the market system that incorporated the dynamics of the construction activity yielded empirical estimates consistent with the expected theoretical relationships. Sand and gravel demand for "Building Construction" was found to be price elastic while sand and gravel demand in "All Construction" and crushed stone demand were found to be price inelastic. Construction activity was found to be positively correlated to demand for aggregates. The parameter estimate for the price of labor, construction workers wages, was found positively related to quantity of sand and gravel demanded for both "Building Construction" and "All Construction." The coefficient estimate was negative for the crushed stone demand.

Long-run supply of aggregates was found to be price elastic and quantity of sand and gravel supplied was negatively related to the lagged price of crushed stone.

CHAPTER V

ESTIMATION OF SHORT RUN EXTRACTION SUPPLY

V.1 Introduction

In chapter III and IV we presented and estimated a simultaneous equations models for aggregates demand and supply at district levels. The estimated supply curve characterized the relationship between fob prices and quantities of sand and gravel sold. For reasons that will become clear shortly, we will refer to that supply curve as the "delivery supply at mine mouth" (DS). The simultaneous equations model was developed in order to predict district equilibrium prices and quantities. In chapter VI that model will be used to assess regional trade. The DS does not, however, represent the relationship between fob prices and quantities produced. Minerals stockpiling plays a major role in supply, and therefore, quantities produced in a given year may not reach the market immediately. The results of a survey administered to sand and gravel producers in five southern states of the U.S. will be used in this chapter to determine the "extraction supply at mine mouth" (ES). We expect extraction supply to be less elastic, than delivery supply in any period since the later includes inventory adjustments.

This chapter is organized as follows: Section V.2 will briefly describe the survey. Survey responses to questions

relating to costs and production will be used for the remainder of this chapter. Section V.3 presents an engineering estimation of ES from these survey data.

V.2 The Operator Survey of Sand and Gravel Producers Alabama, Arkansas, Louisiana, Mississippi, and Texas

A producers' survey was conducted in the states of Alabama, Arkansas, Louisiana, Mississippi, and Texas during Spring 1992. The questionnaire was divided into five major areas and included a total of 14 questions. The topic areas covered were: a) Site Information, b) Operating Information, c) Capital Equipment, d) Shipment Distances, and e) Reclamation Costs. A copy of the questionnaire has been included in Appendix A for the reader's reference.

A trial mailing was sent to 5 operators in the state of Louisiana. There was only one response. However, it was clear that some minor changes were required to clarify some questions and to introduce the survey to potential respondents in order to increase response rates. The first complete mailing was sent to 568 operators in the 5 states, including the 4 operators from LA that had not answered the trial mailing. Names and addresses of operators for the survey were obtained from the Department of Labor, Mine Safety and Health Administration, Metal/NonMetal Mine Safety and Health. By Federal law all operators must be registered with the Mine Safety and Health Administration. Therefore,

the mailing surveyed the entire population of the five states. A follow-up mailing to non-respondents was conducted within a period of three weeks after the first mailing. Table V.1 presents the numbered of operators surveyed by state and the corresponding response rates.

Table V.1

Number of Operators Surveyed by State and Total Responses

State	Total # of Operators Surveyed	# of Responses 1st Mailing responses	2nd Mailing responses	Total[1] #	%
Alabama	78	10	9	19	24%
Arkansas	67	8	6	14	21%
Louisiana	95	12	11	23	23%
Mississippi	82	23	9	32	39%
Texas	243	26	25	51	21%
Total	568	79	60	139	24%

Tabulated responses to each question, by state and district, are presented in Appendix B, Tables B.1 to B.5. These Appendix tables report the following statistics for each district and survey question: the minimum reported value, maximum reported value, and mean. Reference maps of the districts in each state have been placed in Appendix C for the reader's reference. The most commonly unanswered questions were those relating to operating information, capital equipment, and reclamation costs.

1 The percentage corresponds to responses where at least one question was filled out.

V.3. An Engineering Extraction Supply Curve for Sand and Gravel Operators

Even though the small number of responses to the survey does not allow for analysis at district levels, the collected information allows for an analysis at a more aggregated level. In order to conduct the supply analysis at a more aggregated level we assumed homogeneous cost functions across districts in a state as well as across states in the region. Operating costs (OC) was defined as:

OC_i =(Number of production and maintenance personnel * number of hours/shift * number of shifts per day * number of operating days/year*wage) + Fuel + Electricity.

Output was calculated by multiplying the number of acres mined by the depth of mining (thickness of the seam). Output was scaled to cubic yards.

Two major questions were addressed in establishing the cost functions: a) Whether there are operating economies; and b) Whether geological factors are important determinants of operating costs.

V.3.1 Empirical Evidence of Operating Economies in the Sand and Gravel Industry

In order to test for the presence of operating economies we calculated operating costs, as explained above, and estimated the following operating cost functions with

the full sample for all districts and states combined[2]. (probability values in parenthesis):

$$OC_i = 95{,}800.10 + 755.51Q_i - 0.189\,Q_i^2 \qquad (23)$$
$$(0.0466) \quad (0.00010) \quad (0.001)$$
$$R^2 = 0.325 \qquad N=90$$

$$LN(OC_i) = 8.858 + 0.599LN(Q_i) \qquad (24)$$
$$(0.0001) \quad (0.0001)$$
$$R^2 = 0.351 \qquad N=90$$

Both functional forms imply the presence of operating economies as indicated by the signs and significance of the quadratic and logarithmic.

V.3.2 Empirical Relationships between Operating Costs and Geological Characteristics of the Site

It has been argued in the literature that the per unit cost of mining depends on geological factors and output (Zimmerman, 1978). Among the most important geological characteristics for surface mining are depth of overburden and thickness of seam (or depth of mining). For sand and gravel an important determinant of costs may be the percentage of aggregate in the deposit (Bureau of Mines, Mineral Commodity Profiles, 1978). From the survey we obtained data on several geological characteristics of the site. In order to empirically assess the importance of

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[2] We tried estimating separate costs functions for each state but the small number of observations yielded meaningless results

geological factors we estimated the following models using all responses combined (probability values in parenthesis):

$$OC_i = -\underset{(0.634)}{40{,}712.4} + \underset{(0.0001)}{690.2\, Q_i} - \underset{(0.0027)}{0.177\, Q_i^2} + \underset{(0.0806)}{2{,}510.19\, PERCT_i}$$

$$-\underset{(0.4235)}{1{,}507.7\, THICK_i} + \underset{(0.0154)}{10{,}742.25\, OVBDN_i} \qquad (25)$$

$$R^2 = 0.385 \quad N=89$$

and

$$LN(OC_i) = \underset{(0.0001)}{8.24} + \underset{(0.0001)}{0.519\, LN(Q_i)} + \underset{(0.0057)}{0.409\, LN(PERCT_i)}$$

$$-\underset{(0.1621)}{0.296\, LN(THICK_i)} + \underset{(0.0068)}{0.313\, LN(OVBDN_i)} \qquad (26)$$

$$R^2 = 0.441 \quad N=89$$

The presence of operating economies is again evident in these equations. The results also suggest that geological characteristics of the site are important determinants of cost. First, the higher the percentage of gravel (versus sand) the higher the total operating costs. The intuition is that processing costs increase with higher percentages of gravel in the deposit since the material mined must be transported to processing plants. Sand is often left as waste in piles adjacent to the mined area. Second, a deeper deposit, measured by the depth of overburden, is positively correlated with higher operating costs. Overburden is the volume of soil on top of the deposit. It is reasonable that operating costs would be higher with thicker overburden. Third, the thickness of the seam (depth of mining) is negatively related to operating costs. The intuitive

reasoning is that a thicker seam is an indication of a richer deposit. With a rich deposit, equipment can be stationed for a longer period in a particular location reducing the need to move the machinery and to remove overburden. However, the thickness variable was not significant.

V.3.3 Estimation of the Extraction Supply

The procedure used in this section is based on that used by the Energy Information Administration for the estimation of step supply engineering functions in PIES and RAMC[3].

The survey questions on geological characteristics gave the respondent ranges of values to choose from. For example, in question 1 the choices were seven ranges of "Percentages of Aggregate". Since Percentage of Aggregate and Depth of Overburden were significant in the estimated equations above, equations (25) and (26), we use these two variables to distinguish mine qualities. We grouped response ranges for these two variables into three possible classes of "Percentage Aggregate" and three possible classes of "Depth of Overburden". Output was divided into four possible ranges. The first two ranges we created for output

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[3] A brief descriptions of these projects can be found in Chapter II of this document.

were small intervals, allowing for the fact that per unit costs decrease sharply with output for low output levels.

The sample frequency distribution across classes of "Percentage of Aggregate," "Depth of Overburden," and "Output" were established[4]. This represented the number of mines in the sample that fell within a given output, percent aggregate, and overburden class. Each one of the resulting thirty six cells[5] is considered a mine type. The proportion corresponding to a given mine type can be found by dividing the number of sample mines in a cell by the total sample size. Excluding 5 mines that had missing values for one geological factor, the total usable sample was 134 mines.

The expected number of mines from the entire population in each one of the thirty six mine types was calculated for each state by multiplying the cell proportion corresponding to a given mine type by the total number of mines in state. The expected total output for any given mine type in each state is simply estimated by the number of mines in each mine type times the output of the output class.

The average variable cost per mine type is defined as the sum of the per unit operating cost plus the per unit

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4 The geological factor "depth of mining" (thickness of seam) was excluded from this exercise for two reasons; the first, adding a fourth dimension will highly increase the occurrence of cells with zero frequency, and second, the empirical evidence seems to suggest that thickness is not significant in explaining operating costs.

5 Thirty six is all the possible combinations

reclamation cost. Several considerations are in order before we continue. First, given the data restrictions, we must settle for one average variable cost for each different mine type and assume average cost to be constant across states. Second, per unit reclamation costs were not included for the estimation of the operating costs functions above, and must be added to create average variable costs. The reason for not including the reclamation costs for the estimation of the average operating costs is that reclamation costs vary with the number of acres mined, but are less likely to vary with mining depth. The geological sources of variation in reclamation costs is different from those of operating costs[6]. We estimated the following model for reclamation costs (probability values in parenthesis):

$$RC_i = \underset{(0.44)}{1136.8} + \underset{(0.0001)}{29.64\, Q_i} - \underset{(0.005)}{0.005\, Q_i^2} \qquad (27)$$

$$R^2 = 0.4707 \quad N=125$$

and

$$LN(RC_i) = \underset{(0.0001)}{4.432} + \underset{(0.0001)}{0.770\, LN(Q_i)} \qquad (28)$$

$$R^2 = 0.5954 \quad N=125$$

where, RC_i = Total reclamation costs

Excluding the geological factor "Depth of Mining" in the determination of the mine types implies that we had to estimate a restricted version of the operating cost model:

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[6] The Energy Information Administration also handles reclamation costs separately from regular operating costs.

$$OC_i = -\ 62{,}907.7 + 646.5\ Q_i - 0.1647\ Q_i^2$$
$$(0.437) \quad (0.0001) \quad (0.003)$$

$$+\ 2{,}404.4\ PERCT_i + 9{,}289.39\ OVBDN_i \qquad (29)$$
$$(0.091) \quad (0.02)$$

$R^2 = 0.381 \quad N=89$

and

$$LN(OC_i) = 7.81 + 0.437\ LN(Q_i) + 0.400\ LN(PERCT_i)$$
$$(0.0001) \quad (0.0001) \quad (0.0070)$$

$$+\ 0.313\ LN(OVBDN_i) \qquad (30)$$
$$(0.016)$$

$R^2 = 0.428 \quad N=89$

AVC turned out to be negative for several mine types using the quadratic approximation, equation (29). Therefore, the logarithmic approximation, equation (30) was used.

The procedure for estimating the industry AVC curve was as follows. First, the average variable costs is the sum of per unit operation costs plus per unit reclamation costs, AVC = AOC + ARC. Reclamation costs are constant for all mine types within an output class, regardless of depth of overburden or percentage of aggregate. Second, mine types and their corresponding total output for each state were sorted in ascending order from the lowest to the highest AVC. AVC was then plotted against the cumulative sum of output for each mine type in a state. This procedure is illustrated in Figure V.1. The assumption is that each mine type has a constant AVC up to a fixed capacity, Q_i. This assumption is reasonable for a mine since capacity and costs are bounded by equipment capacity.

Figures V.2 to V.6 show the resulting step AVC functions for each state. The AVC for each mine type is constant across states by assumption. The source of differences in the step functions is the level of output for each mine type, which depends on only the total number of producers in each state.

The reasoning for relating the AVC to supply is a threefold. First, minimum reservation price is equal to AVC. Second, lower prices induce mines to close and supply moves down along AVC. Third, we do not know the shape of the curve above the highest existing AVC. Therefore, AVC shows inframarginal supply. However, it does not consider inventories. The supply with inventories would be represented by S_1, S_2, and S in Figure V.1. The ratio of producers' stockholding to output (seldom available) has been widely cited as a major component of producers' marketing behavior in mineral commodities. It has specifically been cited by the Bureau of Mines as a characteristic of sand and gravel production (Sand and Gravel Mineral Commodity Profile). Researchers have incorporated proxies for this ratio when estimation was based on time series data (Tan,1987 for copper; Rice and Smith, 1977 for oil). Studies focusing on market equilibrium conditions and trade on the other hand, commonly assume perfectly elastic supply curves simply based on these behavioral conditions (Toweh and Newcomb, 1991 for iron

ore). Therefore, the price elasticity of supply that we estimate below represents the "elasticity of extraction supply" and should not be confused with the "elasticity of delivery supply" since they are capturing two entirely different decision-making processes.

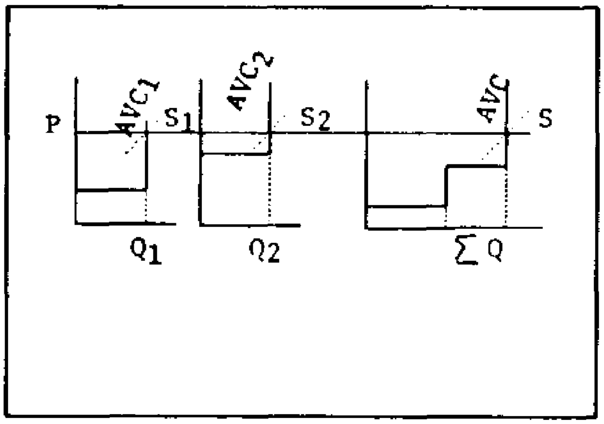

Figure V.1 Illustration of the Procedure for Obtaining the Step Supply Functions

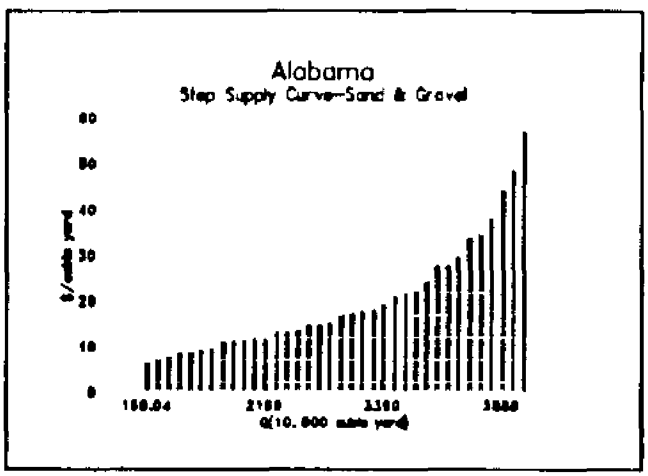

Figure V.2 Step Supply Function for Alabama

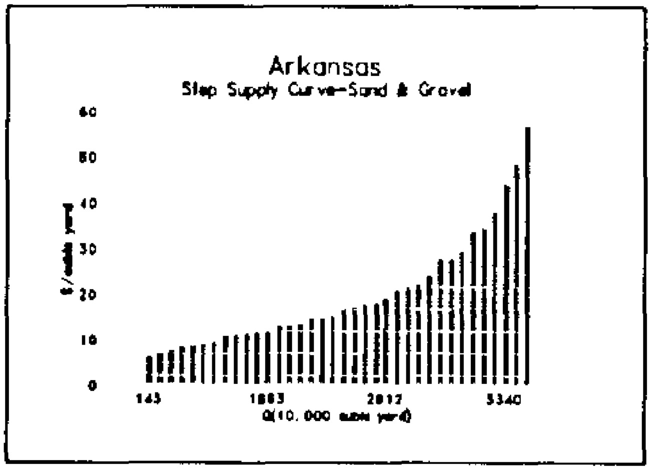

Figure V.3 **Step Supply Function for Arkansas**

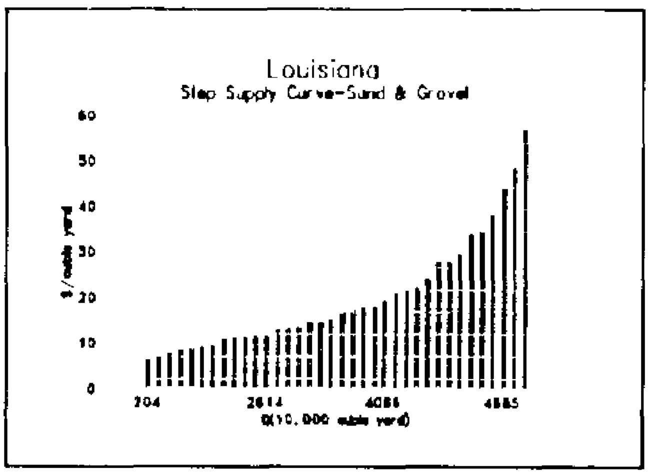

Figure V.4 **Step Supply Function for Louisiana**

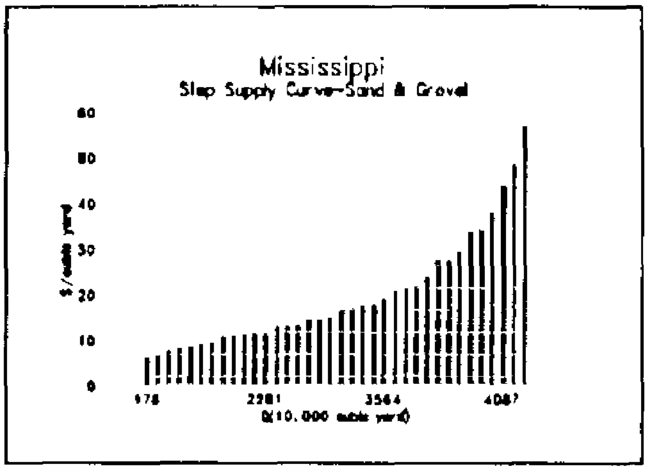

Figure V.5 **Step Supply Function for Mississippi**

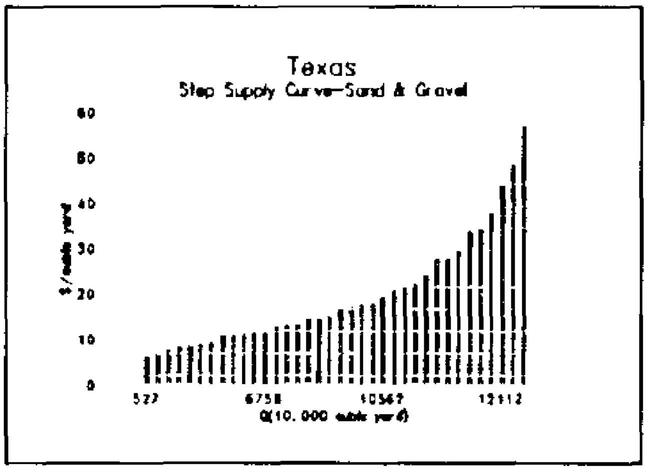

Figure V.6 **Step Supply Function for Texas**

V.3.4 Estimation of the Price Elasticity of Supply

Finally, our task was to estimate a short run price elasticity of supply. This elasticity must be calculated around market clearing prices and outputs. In the survey, this equilibrium price is the AVC of the "marginal mine";

i.e., the operating mine type with the highest AVC in the sample. The AVC calculated from the survey shows: a) AVC for inframarginal mines currently operating in 1992, and b) AVC for the most inefficient mine.

In order to obtain an estimate of the price elasticity of supply, we tried approximating the step supply functions by two continuous functions,

$$AVC= ae^{bQ} \tag{31}$$

$$AVC= cQ^{d} \tag{32}$$

where, AVC is in $/cubic yard, and Q is measured in cubic yards. The estimation is carried out by log-linearizing (31) and (32). The price elasticity of supply is

$\eta = (\partial Q/Q)/(\partial \ln AVC) = (\hat{b}*Q)^{-1}$ in (31) and,

$\eta = (\partial \ln Q)/(\partial \ln AVC) = (\hat{d})^{-1}$ in (32)

Table V.2 shows the actual estimates.

The elasticity is the same across states because the step function for one state is a rescaled version of any other state. Based on the coefficient of multiple determination, R^2, the best approximation seems to be that of equation (31). This empirical result indicates that extraction supply is inelastic to price. The short run inelasticity of extraction supply is consistent with theoretical considerations for extraction of non-renewable resources since short run mine capacity is relatively fixed. This result is not inconsistent with the "delivered elasticity" elasticity of 10.806 estimated in Chapter IV.

Table V.2

Continuous Approximation of the Step Supply Functions

	Coefficients $\hat{a}$	$\hat{b}$	Elasticity η $(Q=Q_{marginal})$	R^2
Equation (31)				
Alabama	1.711 (.0001)	4.3E-08 (.0001)	0.596	0.840
Arkansas	1.711 (.0001)	5.0E-08 (.0001)	0.596	0.840
Louisiana	1.711 (.0001)	3.56E-08 (.0001)	0.596	0.840
Mississippi	1.711 (.0001)	4.09E-08 (.0001)	0.596	0.840
Texas	1.711 (.0001)	1.38E-08 (.0001)	0.596	0.840
Equation (32)				
Alabama	-6.723 (.0001)	0.5664 (.0001)	1.765	0.6456
Arkansas	-6.636 (.0001)	0.5664 (.0001)	1.765	0.6456
Louisiana	-6.828 (.0001)	0.5664 (.0001)	1.765	0.6456
Mississippi	-6.751 (.0001)	0.5664 (.0001)	1.765	0.6456
Texas	-7.366 (.0001)	0.5664 (.0001)	1.765	0.6456

First, as we mentioned in Chapter IV, the supply curve estimated with a cross-section of districts without controlling for the amount of capital in production is capturing long run supply. Second, availability of inventories increases the elasticity of delivery supply. We expect the short run "delivery supply" to be more elastic than "extraction supply."

V.4 Summary of Findings

A sand and gravel producers' survey was conducted in the states of Alabama, Arkansas, Louisiana, Mississippi, and Texas during Spring 1992 with an overall response of 24%. The data collected through the survey was used to estimate an operating cost function. Empirical findings suggest that there are operating economies and that geological characteristics of the site are important determinants of costs. A short run extraction supply by state was estimated by defining thirty six different "mine types." Mine types were defined by geological characteristics. A continuous approximation of the step supply functions allowed us to obtain an estimate of the short run extraction supply. The empirical results indicate that extraction supply is inelastic to price.

CHAPTER VI

INTERREGIONAL TRADE

VI.1 Introduction

In Chapter III we formally presented the theoretical framework for the study of spatially separated markets. The model is constructed to allow trade to occur across districts. In Chapter IV we estimated the district level demand and supply functions for aggregate materials. The presence of transportation costs between districts will constrain trade even if there are market price differentials. In this chapter we present the results of the application of the interspatial quadratic programming model outlined in Chapter III. We use the estimated supply and demand equations from Chapter IV. The programming algorithm finds market clearing prices and quantities. Trade flows are established by maximizing Net Social Pay-Off (a welfare concept defined in Chapter III) across districts.

We pointed out in the introduction to Chapter IV that a trade model needs an estimated domestic, or autarchic, supply and demand. Observing producers' sales at mine-mouth provided us with an estimated domestic supply. However, these sales data are the sum of domestic (within district) plus export (to other districts) demand. Therefore, the demand curve estimated with mine-mouth data was, in principle, the sum of domestic and export demand at fob

prices. If actual trade activity across districts is high, observing mine-mouth sales constitutes a major problem in estimating domestic demand.

The chapter is organized as follows: Section VI.2 outlines the application of the quadratic programming problem for the specific case of aggregates markets. Section VI.3 presents the results of running this model with actual transport costs. Section VI.4 relates the model findings to the results of the survey.

VI.2 Interregional Trade of Sand and Gravel

The application of the quadratic programming algorithm requires a linear demand and a linear supply expressed in inverse form, that is p=f(q). Let demand and supply relationships be represented in their inverse forms as:

$$p_i = K_{di} + [1/(-\beta_i)]d_i \qquad (33)$$

and

$$p_i = K_{si} + [1/(\gamma_i)]s_i \qquad (34)$$

where, K_{di} and K_{si} are constants, d_i and s_i are quantities demanded and supplied, respectively. K_{di} and K_{si} capture the intercept of the demand and supply equations, respectively, evaluated for district i. They are allowed to differ across districts. In addition we are restricted to assuming that $\beta_i = \beta$ i=1,2,..,n, and $\gamma_i = \gamma$ i=1,2,..,n.

The most useful feature of the programming algorithm is the fact that for a set of expected socio-economic variables

(construction activity, wages in the construction industry, and the lagged price of crushed stone), the autarchy equilibrium (price and quantity) for sand and gravel can be predicted. By adding transportation costs, after trade clearing prices, quantities, and trade flows can be determined by a non-linear algorithm that maximizes Total Pay-Off (Samuelson, 1952) minus transportation costs. The objective function is quadratic, and it has been shown to possess a unique maximum (Takayama and Judge, 1964). This was explained in Chapter III.

In order to make the interspatial model operable, transportation costs must be estimated. In 1991, the Bureau of Mines had recorded the method of transportation for 54% of the total construction sand and gravel sold or used by producers in the East South Central region of the U.S. (Division of Industrial Mines, June 1992). The distribution by method of transportation was as follows: Truck, 72%; Water, 5%; Rail, 1%; Not transported, 19%; Other, 2%. Trucking is clearly the dominant method of transportation in the East South Central Region.

A small telephone survey of locally owned trucking companies revealed that truckers seldom contract beyond 150 miles for haulage of aggregates. One of the largest contracting companies in the region, Barber Brothers, provided us with the formula they used to calculate the per ton per mile transportation cost for sand and gravel. This

formula is presented in Table VI.1. The formula stops at 150 miles, and they stated that they do not truck beyond that limit.

Table VI.1

Sand and Gravel Trucking Rates, June 1992

MILES	FORMULA PER TON*
0 - 60	1.70 + (0.0317 * miles) +10%
61 -70	2.66 + (0.0258 * miles) +10%
71 -79	2.90 + (0.0258 * miles) +10%
80 -89	3.32 + (0.0258 * miles) +10%
90 -99	3.42 + (0.0258 * miles) +10%
100 - 120	3.52 + (0.0258 * miles) +10%
121 - 140	3.68 + (0.0258 * miles) +10%
141 - 150	3.84 + (0.0258 * miles) +10%

Source: Ron Normand, Barber Brothers Construction

* The average size truck is 25 tons

Based on the formulas in Table VI.1 we estimated transportation costs for ranges between 5 miles and 150 miles. The results are plotted in Figure VI.1. Costs ranged from $ 0.41 to $0.056 per ton mile.

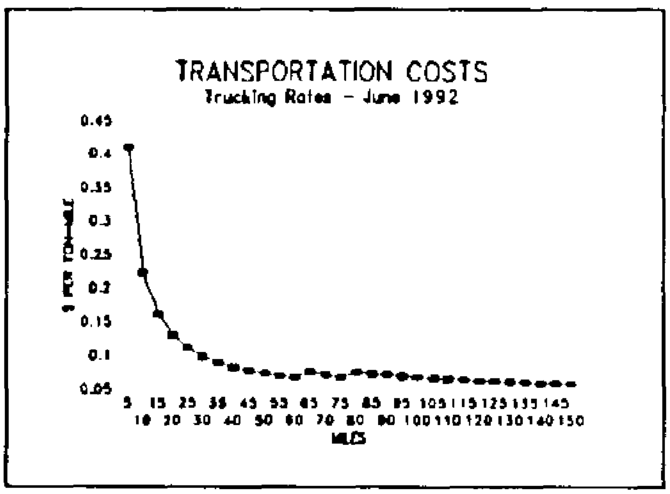

Figure VI.1 **Per ton mile Transportation Costs**

The plot indicates that unit transportation cost sharply decreases with distance. Similar transportation cost patterns exists for other commodities (Heady and Srivatava, 1975).

VI.3 Assessment of Trade of Sand and Gravel across Districts

A region consisting of nine districts was defined for five states: Alabama, Arkansas, Louisiana, Mississippi, and Texas. The region was defined by taking Louisiana as the center and including all adjacent districts in bordering states. Therefore, some districts for non-Louisiana states were excluded. We denote the districts by R1 to R9 to simplify further reference. The nine included districts are defined as follows for use in the programming model:

R1:TEXAS - District 6

R2:TEXAS - District 8

R3:ARKANSAS - District 2

R4:LOUISIANA - District 1

R5:LOUISIANA - District 2

R6:MISSISSIPPI - District 2

R7:LOUISIANA - District 3

R8:MISSISSIPPI - District 3

R9:ALABAMA - District 3

These districts can be identified from the reference map in Appendix C.

In order to calculate transportation costs we had to determine the distance between regions. Most studies of minerals trade and transportation use the distance from center to center of each region, following Henderson (1952). Knowing that trucking is the principal method of transportation, we determined the center of each district and then found the minimum distance between centers by following major paved roads. The distance matrix is presented in Table VI.2

Table VI.2

Highway Milage Between Districts

	R1	R2	R3	R4	R5	R6	R7	R8	R9
R1	0								
R2	161	0							
R3	249	410	0						
R4	144	288	178	0					
R5	229	214	288	110	0				
R6	335	479	302	191	226	0			
R7	369	325	403	225	111	116	0		
R8	418	468	385	274	254	83	143	0	
R9	559	609	526	415	395	224	244	141	0

Observation of the distances in Table VI.2 suggests that it will be unlikely that trade across districts would take place given the current method of transportation. Note that the formulation of the transportation costs in this model is not designed to account for domestic (within district trade) since the distance from district i to district i is set to zero. In addition there is no way to allow for short haul trades between districts since district centers are used to calculate distances.

We calculated the transportation cost per ton between districts by inserting the number of miles from Table VI.2 into the corresponding formula from Table VI.1. Restrictions were imposed for no trade when distances exceeded 150 miles.

Based on the estimated demand and supply functions from Table IV.2 and Table IV.4, the values of K_{di} and K_{si} in (33) and (34) are calculated as follows:

Sand and Gravel "Building Construction"[1]:

$$K_{di} = (-1.0168 + 0.3557 \ln(\hat{c}_i) + 1.7505 \ln(w_i))/-1.3209 \quad (35)$$

$$K_{si} = (-0.8076 - 2.1653 \ln(q_{i,t-1}))/8.3369$$

Sand and Gravel "All Construction"[2]:

$$K_{di} = ((-2.1015 + 0.2183 \ln(\hat{c}_i) + 2.6169 \ln(w_i))/-0.7988 \quad (36)$$

$$K_{si} = (-2.2706 - 1.9487 \ln(q_{i,t-1}))/10.8066$$

Crushed Stone:

$$K_{di} = (7.7585 + 0.4360 \ln(\hat{c}_i) - 1.0104 \ln(w_i))/-0.8534 \quad (37)$$

$$K_{si} = (-6.04924 - 0.5858 \ln(p_{i,t-1}))/2.3263$$

where Actual values for $\hat{c}_i$, w_i, $q_{i,t-1}$, and $p_{i,t-1}$ are used for each district i.

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[1] For definition of what is included in "building construction" see Chapter IV.

[2] See footnote 1.

The interspatial model was programmed with the computer package GAMS version 2.05[3]. The trade model was calibrated for 1988. We deflated transportation costs using the fuel price index (Bureau of Labor Statistics,1992). The algorithm consists of three parts. First, intercepts and slopes of demand and supply functions are entered for all regions together with a matrix of transportation costs. Second, a small linear program finds starting values by maximizing output subject to supply being equal to demand for all regions. This small job is basically designed to provide starting values for the next part. Third, a non-linear program maximizes net social pay off[4]. This optimization yields three sets of results: a) Autarchy prices and quantities, b) Market clearing prices and quantities after trade, c) A matrix of shipments across regions.

The algorithm was executed for "Building Construction," "All Construction," and crushed stone estimated models, separately. An optimal solution was found in the three cases. The solution showed that shipments were to occur only from region i to region i, that is there was no trade. This is not an unexpected outcome given our previous

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[3] GAMS stands for General Algebraic Modeling System. Several practical applications can be found in Jefferson and Boisvert, 1989.

[4] The objective function was presented in Chapter III.

discussion regarding distances across districts. There are predicted and actual autarchy price differentials across districts. However, trucking 100 miles costs $ 4.96 per ton (by Table VI.1, deflated to 1988 values).

Autarchy equilibrium prices and quantities predicted are shown in Table VI.3 and Table VI.4. The estimated model for crushed stone (Chapter IV) was not reasonable. Coefficients had incorrect sign or were not significant. Possibly because of that reason, the prediction of autarchy equilibrium was very far from actual values. We decided to only present the sand and gravel model in this chapter. The table shows the predicted autarchy prices and quantities, the actual transaction prices, and the actual quantities sold for sand and gravel combined into one aggregate measure. The data used for the estimation of the model in Chapter IV were not reported with price and quantity for sand separated from those of gravel. Therefore, the price shown on Table VI.3 and VI.4 corresponds the fob price of a combined sand and gravel, so it should be interpreted with caution.

Actual market transactions and predicted market equilibrium are not directly comparable since actual transactions may not have been realized under the efficient norm postulated by the model. However, Henderson (1952) suggested a validation exercise based on absolute deviations between predicted and actual values. Henderson was trying

to measure the efficiency of the market by comparing the predicted, and thus efficient, to the actual values. Toweh and Newcomb (1991) applied this validation exercise to their iron ore model. We calculated the absolute value of the deviations between actual and predicted values in Tables VI.3 and VI.4. The average absolute deviation is then used to calculate the percentage of actual prices and quantities explained by the model.

Table VI.3

Sand and Gravel
Actual and Predicted Autarchy Prices and Quantities-1988, By District, using "All Construction"

	District	ACTUAL $Q(10^3$ TONS)	P	PREDICTED $Q(10^3$ TONS)	P	Abs. Deviat. Q	P
R1	TEXAS 6	202	3.75	1,397	3.82	1,195	0.07
R2	TEXAS 8	14,240	2.87	4,888	3.28	9,352	0.41
R3	ARKANSAS 2	2,835	3.63	1,616	3.17	1,219	0.46
R4	LOUISIANA 1	1,113	4.70	1,519	3.56	406	1.14
R5	LOUISIANA 2	850	5.20	2,350	3.71	1,500	1.49
R6	MISSISS. 2	2,579	3.39	1,108	3.46	1,471	0.07
R7	LOUISIANA 3	2,002	2.32	2,114	2.51	112	0.19
R8	MISSISS. 3	1,095	3.69	831	3.12	264	0.57
R9	ALABAMA 3	3,524	5.40	1,253	3.24	2,271	2.16
Average absolute deviation						1,976	0.73
Percentage Explained						62%	81%

By this validation exercise, the results explain 81% of the actual price and 62% of the actual quantity of sand and gravel in "All Construction;" the percentages are 88% of the

actual price and 14% of actual quantity for "Building Construction."

Table VI.4

Sand and Gravel
Actual and Predicted Autarchy Prices and Quantities-1988, By District, using "Building Construction"

	District	ACTUAL $Q(10^3$ TONS)	P	PREDICTED $Q(10^3$ TONS)	P	Abs. Deviat. Q	P
R1	TEXAS 6	52	4.04	465	4.46	413	0.42
R2	TEXAS 8	11,469	2.91	2,417	3.70	12,052	0.79
R3	ARKANSAS 2	2,435	3.72	780	3.56	1,655	0.16
R4	LOUISIANA 1	741	3.88	567	4.08	174	0.20
R5	LOUISIANA 2	581	4.59	1,081	4.41	500	0.18
R6	MISSISS. 2	1,402	3.47	548	4.07	854	0.60
R7	LOUISIANA 3	1,150	2.52	1,318	2.61	168	0.09
R8	MISSISS. 3	780	4.01	409	3.51	371	0.50
R9	ALABAMA 3	2,631	2.93	682	3.73	1,949	0.80
Average Absolute Deviation						2,015	0.41
Percentage Explained						14%	88%

A sensitivity analysis was performed by decreasing the distance between adjacent districts to one half. No trade was found across districts. The shortest distance for this scenario was 41.5 miles, between R6 and R8 (Mississippi Districts 2 and 3, respectively). In 1988 prices transportation costs were $ 2.98 per ton for that distance. The price differentials between these two regions, Tables VI.3 and VI.4, make it clear that no trade could take place.

Finally, the survey of producers showed that on average, 80% of the shipments were less than 75 miles. These responses are shown in Table VI.5 below. In Louisiana, 100% of the deliveries originating from districts 1 and 2 were less than 50 miles. These results are absolutely consistent with our expectations. They are also consistent with the results of the empirical model, which predicts price differentials between districts that are too low to stimulate trade between districts.

Table VI.5

Sand and Gravel

Percentage of Product Shipped by Distance

	Miles Shipped							
Region	0-10	10-20	20-30	30-50	50-75	75-100	100+	# of Responses
R1	51	3	3	0	0	0	43	2
R2	11	23	20	5	29	8	3	11
R3	28	9	3	14	15	8	23	9
R4	7	20	7	66	0	0	0	3
R5	24	58	14	4	0	0	0	6
R6	19	21	38	19	2	1	0	8
R7	7	20	7	18	20	20	8	13
R8	9	17	22	25	10	10	7	11
R9	26	15	18	10	7	9	14	11

Source: Sand and Gravel Operator Survey.

VI.4 Summary of Findings

This chapter presented the results of the application of an interspatial quadratic programming model. The system of demand and supply equations estimated in Chapter IV was used to predict trade across districts. No trade was found. On average, the predicted autarchy equilibrium price

explained 81% and 88% of the actual price of sand and gravel in "All Construction" and "Building Construction," respectively. The predicted autarchy equilibrium quantity explained 62% and 14% of the actual quantity. The results of the producers' survey indicated that 80% of the yshipments were, on the average, less than 75 miles. For two Louisiana districts, 100% of the shipments were less than 50 miles.

CHAPTER VII

CONCLUSIONS, IMPLICATIONS, LIMITATIONS, AND FURTHER RESEARCH

In an effort to jointly deal with the accumulation of industrial waste and the exhaustion of natural resources, engineers are developing recycled phosphogypsum based materials. Phosphogypsum is a by-product from the production of phosphate based fertilizers. Recycled phosphogypsum based materials are expected to be substitutes for traditional construction aggregate materials such as sand, gravel, and crushed stone, generally known as aggregates. This study focused on modeling the markets for those traditional construction materials as an indirect assessment of the possible market for the recycled phosphogypsum products. The study did not, however, attempt to address the important issue of market acceptance of phosphogypsum materials.

Aggregates are used as inputs in the construction of highways, buildings, fill, and several other outputs. Unlike markets for more valuable minerals, markets for aggregates have received little attention in past research. Reasons for this may be the historical abundance of these materials. The markets for these materials have important spatial delineations due to high transport costs relative to the mineral value. The availability of aggregate reserves

is limited locally and subject to increasing extraction costs as the most efficient reserves are mined first. Deposits vary with respect to the cost of extraction and quality of the mined material. The availability of aggregates to the market in the short run is influenced by large holdings of inventories.

VII.2 The Modeling Procedure

By specifying a production function for construction activity, we derived an input demand function for aggregates. Demand was a function of the price of aggregate, construction wages, and construction activity. Construction activity was further specified as depending on a dynamic adjustment of capital infrastructure. The mine-mouth supply of aggregates and a short run extraction supply were developed. A simultaneous equations model for the equilibrium between supply and demand for aggregates, at mine-mouth, was estimated. Extraction supply was estimated using an engineering-based cost approach. Finally, transportation costs were included, and regional trade was evaluated within the framework of a spatial equilibrium model.

Construction of buildings, roads, etc. is a reflection of actual changes in infrastructure stock. A desired amount of infrastructure stock was modeled as depending upon population and per capita income. The actual amount of

infrastructure stock was defined as being equal to the actual amount of stock in period t-1 minus the depreciation plus the current construction activity. However, only a fixed fraction of the desired adjustment between actual and desired stocks is achieved in one period. Data limitations prevented the incorporation of this dynamic specification directly into the demand equation. Therefore, a two step estimation procedure was used. First, the reduced form of the dynamic specification for construction activity was estimated at the U.S. level by assuming homogenous preferences for construction across the country. The reduced form specification depended on past construction activity, per capita income, and population. Per capita income was determined to be non-stationary by testing for the presence of a unit root. Therefore, the model was estimated with population and past construction activity in levels, and per capita income in first differences. The second step of the estimation procedure was to incorporate parameter estimates from step one into the demand equation for the cross-sectional estimation of supply and demand.

VII.3 Estimates of Long-Run Demand and Supply Elasticities

The domestic demand and supply functions were estimated using Bureau of Mines districts level data. Demand for aggregate was derived from a Cobb-Douglas production function for construction activity. This input demand

depended on construction activity, the fob price of aggregate, and the wages of construction workers. Construction activity was replaced by its prediction based on population, changes in per capita income, and past construction activity for each district. A mine mouth supply was specified by exploiting the rivalry in the use of the same inputs of production between the sand and gravel and crushed stone industries. Quantity supplied was modelled as depending upon the ratio of the own price to the lagged price of the other output. Due to data limitations, it was not possible to control for the quantity of capital in production or geological qualities. Therefore, this estimated supply was interpreted as representing producers' long run equilibrium.

The autarchy model was estimated using 2SLS on a cross section of districts for forty states of the U.S. The available data was 1988 for sand and gravel and 1987 for crushed stone. We estimated a system of supply and demand for crushed stone, and two systems for sand and gravel. Models of Sand and gravel sold for "All Construction Uses," and sand and gravel sold for "Building Construction Uses" were estimated separately. The reason for the two separate estimations in sand and gravel was that the measure of construction activity did not include highway projects. Therefore, it seemed reasonable to separate building construction uses of aggregate from all uses combined.

The own price elasticities of demand for sand and gravel in "All Construction Uses" was -0.7988, and -1.3209 for "Building Construction Uses." The crushed stone own price was -0.8534. Although the point estimate of demand elasticity for "Building Construction Uses" is elastic, none of the own price elasticities were significantly different from zero. The parameter estimate for the predicted construction activity variable was positive and highly significant in all cases. We expected relatively inelastic demand for these aggregates since their share of total construction cost is small. The construction wages parameter estimates were positive and significant in the sand and gravel demand equations, however, the estimate was negative and not significant for crushed stone. The estimated own price elasticity of supply for sand and gravel in "All Construction Uses" was 10.8066 and for "Building Construction Uses" was 8.3369, both highly significant. Crushed stone own price elasticity of supply was 2.3263, also significant. We believe the large values for the own price elasticities of supply are due to the long run nature of our estimated supply function. We were unable to hold capital and land fixed because of data limitations; and, these materials are relatively abundant in regions where they are used.

VII.4 Estimating Short Run Extraction Supply

A survey of sand and gravel producers in Alabama, Arkansas, Louisiana, Mississippi, and Texas was conducted during the Spring of 1992. The survey covered the topics of operating costs, reclamation costs, geological characteristics of the site, and shipment distances. The overall percentage of response was 24% and the number of responses was 139 for the five states region. The number of observations by states was relatively small and we were forced to undertake our analysis on a regional bases. We estimated operating cost functions. Our results indicated the presence of operating economies. Also geological quality of a site, measured by depth of overburden and percentage of aggregate, were important determinants of operating costs. Similar results have been found in surface coal mining.

Using the estimated cost functions, we estimated an engineering step supply function for each state. We defined thirty six different mine types based on geological characteristics and output ranges. Average cost was defined as the sum of the operating costs per unit of aggregate produced plus the reclamation costs per unit. Both were estimated from cost functions. The engineering step supply functions were calculated for each state by estimating the expected number of mines and total output of each mine type by state. Mine types were ranked from the lowest to highest

variable cost. The step supply was the relationship between the average cost and the cumulative output. Continuous approximations of these step functions were used to estimate a short-run elasticity of extraction supply. This estimated elasticity was 0.60. The inelastic short run supply is consistent with theoretical considerations since extraction of non-renewable resources in the short run is characterized by the fixed capacity of existing mine sites and the capital intensive nature of the production process. Short run supply elasticity may exceed this extraction elasticity, since stockpiling of inventories is possible.

VII.5 Interregional Trade

Transportation costs were introduced together with the estimated system of supply and demand equations into a Samuelson-Enke type spatial equilibrium model. This spatial equilibrium model was developed for a region including Louisiana at the center and adjacent districts of Texas, Arkansas, Mississippi, and Alabama. Highway distances from center to center of the districts were calculated. The interspatial trade algorithm was designed with two steps. First, given values for the exogenous variables in the system it could locate the predicted autarchy equilibrium prices and quantities. Second, it searched for possible trade and, if any, it found the after trade clearing prices and trade flows. However, in this application there was no

trade. We believe these results are explained by the high per ton mile cost of trucking, the dominant form of transportation in the region. Transportation costs exceeded price differentials across districts. This result was confirmed by the producers' survey. Survey results indicated that for 1991, 80% of the shipments travel less than 75 miles. For the specific case of two of the Louisiana districts, all the shipments travel less than 50 miles. The distances between district centers exceeded 100 miles in all but for one case.

The predicted autarchy equilibrium prices were compared to actual transaction prices for 1988 by calculating a measure of efficiency developed by Henderson (1952). On average, the model explained 81% and 88% of actual prices for "All construction" and "Building Construction," respectively. The percentage of the actual quantities explained by the predicted equilibrium were 62% and 14% for "All Construction" and "Building Construction," respectively.

VII.6 Importance of these Results for Recycled Phosphogypsum Materials

The relevant question for phosphogypsum producers is whether there is room in the market for their materials. Clearly the after entry price must be larger than the delivered cost to the phosphogypsum producer. The worst

scenario for entry is one where demand and supply are both inelastic. The reason is that augmented supply will cause dramatic decrease in price, compared to scenarios where either demand or supply is elastic. According to our findings this is precisely the current scenario for the short run market environment. Outlooks in the long run are only slightly better since supply is highly elastic.

This study did not address the availability of future reserves of aggregate due to the fact that such data are not available as they are for more valuable, less abundant minerals such as coal, oil, and gas. Environmental concerns could increasingly limit access to riverine minerals deposits and will make all mining operations more expensive. Although there is a small degree of importation of crushed stone, it currently constitutes an insignificant portion of the aggregate markets. In contrast to the arguments suggesting interpretations of increasing scarcity of aggregates, we learned that the traditional aggregate is plentiful enough currently and pervasively available. Geological structures in LA support the likely abundance of these aggregates.

High transport costs dwarf price differentials, resulting in the formation of highly localized markets. Our evidence suggests that aggregates seldom are transported more than 75 miles. Of course, this distance shipped will be a function of localized scarcities.

The above arguments suggest selective market entry for phosphogypsum based aggregates substitutes: finding geographic areas where there is evidence of regional shortages of traditional construction aggregates. In targeting a geographic area for entry, there must be allowance made for the likely dramatic reduction in prices below observed pre-entry prices when a substantial quantity of new supply is considered.

At the risk of stating the obvious, phosphogypsum based aggregates and traditional aggregates may not be viewed by the consumer as perfect substitutes. Recycling phosphogypsum into construction materials, while technically feasible, could face resistance by consumers. Both the actual or perceived unknown structural characteristics associated with the introduction of any new product may require a risk-based discount for these new materials below traditional materials prices. Actual or perceived uncertainties associated with the environmental properties of these new products may require additional discounts. Even the approximate magnitude of these discounts is unknown at this time. This issue of substitutability may be even more important to the marketability of this new material than the availability of potential entry markets.

The supplier of this new phosphogypsum based product must ask itself what its minimum supply price for this product would be. This may include selling the product in

markets below the processing and transport costs necessary to reach those markets. It may even include paying individuals to take the material. This all depends upon the profits obtainable from continuing to produce and generate waste in current locations.

VII.7 Limitations and Recommendations for Further Research

One of the major limitations for our modeling was the availability of data. The Bureau of Mines reporting system by districts started in 1985. Sand and gravel figures are published for even years and crushed stone figures for odd years. Time series data are available only at the state level. Moreover, the only data available is on total quantity and total value. For sand and gravel, it would be better if sand were reported separately from gravel since, in practice, they are sold separately and have very different values and abundance.

Estimation of short run supply could be undertaken if data were available on capital investment and mining costs. The most important missing variable on the supply side was geological quality of sites. Ideally, a pooled time series and cross-sectional sample would improve efficiency by allowing the specification of an error components model. A fruitful avenue for research in the absence of a pooled sample is that of MIMIC models in the context of simultaneous equations models. Additional available

information could be used to estimate the variance of the measurement error. With an improved specification of the supply side of the market, efficiency of estimation could also be improved by using a system estimator instead of a single equation estimator. The step supply functions estimated in this study are very restrictive since they assumed homogeneity across states. Finally, a superior model would have fully all stages of supply from production to delivery. The demand side should model separately the different types of construction activities, in a fashion similar to that used by Rice and Smith (1977) for the petroleum industry.

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APPENDIX A

I. Site Information

1. Please check the approximate range of percent aggregate at this site:

Percent of Aggregate

0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	More Than 60

2. Please check the approximate depth of active mining at this site:

Depth of Active Mining

Less than 20'	20-30'	30-40'	40-50'	50-60'	60-70'	70-80'	Deeper Than 80'

3. What is the approximate overburden at this site?

Depth of Overburden

0-2'	2-4'	4-6'	6-8'	8-10'	10-15'	15-20'	20-25'	More than 25'

4. Please check the primary method of overburden removal, and note whether that overburden is primarily sold from this site.

Primary Method for Removing Overburden			Is Overburden Primarily Sold?	
Strip	Process	**********	Yes	No
		**********		

5. Please check the approximate remaining years left, assuming current economic conditions, in the "Active Reserves" at this site; and remaining years in the "Inactive Reserves" that you own or lease adjacent to this site:

Remaining Years in Active ***** Reserves **********   Remaining Years in Inactive Reserves Owned or Leased

0-5 years	5-10	10-15	15-20	20-25	**************	0-10	10-20	20-30	30-50
					*******				

6. Please check the approximate average acres mined in 1991 at this site.

Average Acres Mined per Year

0-5 acres	5-10	10-15	15-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	Above 90

II Operating Information

7. Please provide the following information on employment of production and administrative personnel during 1991 at this site, as well as number of operating days, number of shifts per day, and average hours for each shift at this site in 1991:

Total Employment, 1991   Operating and Shifts, 1991

Production and Maintenance Personnel	Adminisrative Personnel	Number of Operating Days, 1991	Average Number of Shifts per Day	Average Hours per Shift

8. What were 1991 energy costs at this site?

a. Fuel $____________

b. Electricity $___________

III. Capital Equipment

9. What are the total number of on-site trucks currently at this site?

   a. Number of small trucks (pickups, vans, etc.) ________

   b. Number of on-site haulage units in each size class:
      1. less than 25 tons _______
      2. 25-50 tons _______
      3. 50-75 tons _______
      4. 75-100 tons _______

10. How many dozers do you operate on this site, using the following Caterpillar equivalents:
    1. D4 ___
    2. D5 ___
    3. D6 ___
    4. D7 ___
    5. D8 ___
    6. D9 ___

11. What are the total number of draglines, backhoes, shovels and front end loaders in each of the following size classes for this site?

Size Class	Draglines	Backhoes	Shovels	Front End Loader
less than 2 cu yd				
2-4 cu yd				
4-6 cu yd				
6-8 cu yd				
8-10 cu yd				
10 or more cu yd				

12. If this is a hydraulic mine and you operate dredges, how many pumps of the following size and arrangement do you currently use on this site:

Pump Size	Twin Pump	Submersible
6 x 8"		
8 x 10		
10 x 12		
12 x 14		
14 x 16		
16 x 18		
18 x 20		

IV. Shipment

13. Approximately what percent of your product shipments from this site are shipped the following distances:

Distance	% Shipped by Distance
0-10 miles	
10-20	
20-30	
30-50	
50-75	
75-100	
100 or more	

VI Reclamation Costs

14. Reclamation costs are very difficult to estimate. However, could you check an approximate estimate of the per acre reclamation costs at this site, using current dollar costs.

Approximate Reclamation Costs per Acre	
$200-500 per acre	
$500-1000	
$1000-1500	
$1500-2000	
$2000-3000	
Above $3000	

APPENDIX B

Table B.1 **Maximum, Minimum, and Average Response by District - Alabama**

Question	District 1			District 2			District 3		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
% of Aggregate	20-30	20-30	20-30	20-30	60+	30-40	20-30	60+	40-50
Depth of Mining	20-30'	40-50'	30-40'	20-30'	60-70'	40-50'	-20'	50-60'	40-50'
Depth of Overburden	0-2'	2-4'	2'	2-4'	25'+	15-20'	0-2'	10-15'	2-4'
Overburden Removal	Strip	Strip	Strip	Strip	Strip	Strip	Strip	Proc.	Strip
Overburden sold	No	No	No	Yes	No	No	Yes	No	No
Remaining Active Reserves (years)	5-10	20-25	15	0-5	15-20	10-15	0-5	20-25	5-10
Remaining Inactive Reserves (years)	0-10	30-50	20	0-10	30-50	10-20	0-10	30-50	10-20
Acres Mined	10-15	20-30	15-20	0-5	20-30	5-10	0-5	20-30	5-10
Production and Maintenance Personnel	7	12	9	1	6	3	0	19	8
Administrative Personnel	2	2	2	0	1	1	0	3	2
Operating days in a year	225	250	237	160	300	255	170	320	257

(continue Table B.1)

Shift/day	1	1	1	1	1	1	1	1.5	1
Shift hours	8	9	8.5	8	10	9	8	*	
Fuel($)	15,000	70,000	42,500	4,600	50,000	24,750	5,000	120,000	34,000
Electricity	0	0	0	0	12,500	6,375	0	84,000	20,014
# of Trucks	2	3	2.5	0	4	2	0	5	2
Haulage Units									
< 25 tons	0	0	0	0	2	1	0	3	1
25-50 tons	4	4	0	0	4	2	0	5	2
50-75 tons	0	0	0	0	0	0	0	1	0
75-100 tons	0	0	0	0	0	0	0	0	0
Dozers									
D4	0	0	0	0	0	0	0	1	0
D5	0	0	0	0	0	0	0	2	1
D6	0	0	0	0	0	0	0	2	1
D7	0	0	0	0	0	0	0	1	0
D8	1	2	1.5	0	0	0	0	0	0
D9	0	0	0	0	0	0	0	0	0
Draglines									
< 2 cu yd	0	0	0	0	0	0	0	1	0
2-4 cu yd	0	0	0	0	0	0	0	1	0
4-6 cu yd	0	0	0	0	0	0	0	1	0
6-8 cu yd	0	0	0	0	0	0	0	1	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0

(continue Table B.1)

Backhoes									
< 2 cu yd	0	0	0	0	0	0	0	1	0
2-4 cu yd	0	0	0	1	1	1	0	2	0
4-6 cu yd	0	0	0	1	1	1	0	0	0
6-8 cu yd	0	3	1.5	0	0	0	0	0	0
8-10 cu yd	0	1	0.5	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Shovels									
< 2 cu yd	0	0	0	0	0	0	0	0	0
2-4 cu yd	0	0	0	0	0	0	0	0	0
4-6 cu yd	0	0	0	0	0	0	0	0	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Front End Loaders									
< 2 cu yd	0	0	0	0	0	0	0	0	0
2-4 cu yd	0	0	0	0	1	0.5	0	3	1
4-6 cu yd	0	2	1	3	3	3	0	4	1
6-8 cu yd	0	0	0	4	4	4	0	2	0
8-10 cu yd	0	0	0	0	0	0	0	2	0
10+ cu yd	0	0	0	0	0	0	0	0	0

(continue Table B.1)

Twin Pump									
6 x 8"	0	0	0	0	0	0	0	2	0
8 x 10"	0	0	0	0	0	0	0	2	0
10 x 12"	0	0	0	2	2	2	0	3	0
12 x 14"	0	0	0	0	0	0	0	0	0
14 x 16"	0	0	0	0	0	0	0	0	0
16 x 18"	0	0	0	0	0	0	0	0	0
18 x 20"	0	0	0	0	0	0	0	0	0
Submersible									
6 x 8"	0	0	0	0	0	0	0	0	0
8 x 10"	0	0	0	1	1	1	0	1	0
10 x 12"	0	0	0	0	0	0	0	0	0
12 x 14"	0	0	0	0	0	0	0	0	0
14 x 16"	0	0	0	0	0	0	0	0	0
16 x 18"	0	0	0	0	0	0	0	0	0
18 x 20"	0	0	0	0	0	0	0	0	0
Shipment %									
-10 miles	0	5	2.5	0	20		0	100	
10-20 miles	0	5	2.5	0	10		0	80	
20-30 miles	0	20	10	0	100		0	90	
30-50 miles	0	30	15	0	100		0	100	
50-75 miles	40	100	70	0	0		0	50	
75-100 miles	0	0	0	0	0		0	50	
100 + miles	0	0	0	0	90		0	95	
Reclamation Costs per acre in thous of $	0.2-0.5	0.2-0.5	0.2-0.5	0.2-0.5	2-3	0.5-1	0.2-0.5	3+	0.5-1

Table B.2 **Maximum, Minimum, and Average Response by District - Arkansas**

Question	District 1			District 2			District 3		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
% of Aggregate	60+	60+	60+	20-30	60+	50-60	60+	60+	60+
Depth of Mining	60-70'	60-70'	60-70'	-20'	80'+	20-30'	20-30'	50-60'	40-50'
Depth of Overburden	6-8'	6-8'	6-8'	0-2'	15-20'	6-8'	0-2'	15-20'	4-6'
Overburden Removal	Strip	Strip	Strip	Strip	Strip	Strip	Strip	Strip	Strip
Overburden sold	No	No	No	Yes	No	No	Yes	No	No
Remaining Active Reserves (years)	10-15	10-15	10-15	0-5	20-30	10-30	5-10	20-25	10-15
Remaining Inactive Reserves (years)	0-10	0-10	0-10	0-10	30-50	10-20	10-20	10-20	10-20
Acres Mined	5-10	5-10	5-10	0-5	0-5	30-40	10-15	0-5	50-60
Production and Maintenance Personnel	30	30	30	3	31	12	5	12	8
Administrative Personnel	6	6	6	0	4	2	2	2	2
Operating days in a year	250	250	250	52	300	202	240	350	295

(continue Table B.2)

Shift/day	1	1	1	1	1	1	1	1	1
Shift hours	10	10	10	8	38	12	10	10	10
Fuel($)	130,000	130,000	130,000	4,130	130,000	61,233	24,000	25,000	24,500
Electricity	165,000	165,000	165,000	200	300,000	97,385	12,000	80,000	46,000
# of Trucks	7	7	7	0	5	3	1	4	3
Haulage Units									
< 25 tons	0	0	0	0	5	3	0	3	2
25-50 tons	8	8	8	0	2	1	0	0	0
50-75 tons	0	0	0	0	0	0	0	0	0
75-100 tons	0	0	0	0	0	0	0	0	0
Dozers									
D4	0	0	0	0	1	0	0	1	0
D5	0	0	0	0	0	0	0	0	0
D6	0	0	0	0	2	0	0	0	0
D7	0	0	0	0	3	1	0	1	0
D8	1	1	1	0	1	0	0	0	0
D9	0	0	0	0	0	0	0	0	0
Draglines									
< 2 cu yd	0	0	0	0	2	1	0	0	0
2-4 cu yd	0	0	0	0	3	0	0	0	0
4-6 cu yd	0	0	0	0	2	0	0	0	0
6-8 cu yd	0	0	0	0	3	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0

(continue Table B.2)

Backhoes									
< 2 cu yd	0	0	0	0	2	1	0	0	0
2-4 cu yd	0	0	0	0	0	0	0	1	0
4-6 cu yd	0	0	0	0	0	0	0	0	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Shovels									
< 2 cu yd	0	0	0	0	0	0	0	0	0
2-4 cu yd	0	0	0	0	0	0	0	0	0
4-6 cu yd	0	0	0	0	0	0	0	0	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Front End Loaders									
< 2 cu yd	0	0	0	0	1	0	0	0	0
2-4 cu yd	0	0	0	0	3	1	0	3	1
4-6 cu yd	0	0	0	0	4	1	0	3	1
6-8 cu yd	6	6	6	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	1	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0

(continue Table B.2)

Twin Pump									
6 x 8"	0	0	0	0	1	0	0	0	0
8 x 10"	0	0	0	0	0	0	0	0	0
10 x 12"	0	0	0	0	0	0	0	0	0
12 x 14"	0	0	0	0	0	0	0	0	0
14 x 16"	0	0	0	0	0	0	0	0	0
16 x 18"	0	0	0	0	0	0	0	0	0
18 x 20"	0	0	0	0	0	0	0	0	0
Submersible									
6 x 8"	0	0	0	0	0	0	0	0	0
8 x 10"	0	0	0	0	0	0	0	0	0
10 x 12"	0	0	0	0	0	0	0	0	0
12 x 14"	0	0	0	0	0	0	0	0	0
14 x 16"	0	0	0	0	0	0	0	0	0
16 x 18"	0	0	0	0	0	0	0	0	0
18 x 20"	0	0	0	0	0	0	0	0	0
Shipment %									
-10 miles	50	50	50	0	100	29	0	90	30
10-20 miles	20	20	20	0	50	9	0	100	37
20-30 miles	10	10	10	0	15	3	0	10	3
30-50 miles	10	10	10	0	75	15	0	10	3
50-75 miles	5	5	5	0	85	16	0	80	27
75-100 miles	4	4	4	0	50	8	0	0	0
100 + miles	1	1	1	0	85	24	0	0	0
Reclamation Costs per acre in thous of $	1	1	1	1	3	2	1	3	2

Table B.3 **Maximum and Minimum Value and Average Response by District - Louisiana**

Question	District 1			District 2			District 3		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
% of Aggregate	20-30	60+	40-50	10-20	60+	40-50	0-10	60+	20-30
Depth of Mining	-20'	20-30'	20-30'	20-30'	60-70'	50-60'	-20'	40-50'	20-30'
Depth of Overburden	4-6'	10-15'	8-10'	0-2'	15-20'	6-8'	0-2'	10-15'	4-6'
Overburden Removal	Strip	Strip	Strip	Strip	Proc	Strip	Strip	Proc	Strip
Overburden sold	No	No	No	Yes	No	Yes	Yes	No	No
Remaining Active Reserves (years)	0-5	15-20	5-10	0-5	15-20	5-10	0-5	15-20	5-10
Remaining Inactive Reserves (years)	0-10	20-30	10-20	0-10	10-20	0-10	0-10	20-30	0-10
Acres Mined	0-5	0-5	0-5	0-5	15-20	5-10	0-5	40-50	5-10
Production and Maintenance Personnel	1	1	1	1	12	4	1	400	35
Administrative Personnel	1	1	1	1	2	1	0	6	2
Operating days in a year	260	260	260	55	260	185	180	300	240

(continue Table B.3)

Shift/day	2	2	2	1	2	1	1	2	1
Shift hours	8	8	8	6	10	9	8	10	9
Fuel($)	60,000	60,000	60,000	4,850	22,200	13,525	6,652	96,000	37,865
Electricity	.	.	.	0	0	0	0	18,112	4,603
# of Trucks	1	2	1	0	3	1	0	9	2
Haulage Units									
< 25 tons	1	3	2	0	4	1	0	3	1
25-50 tons	1	10	5	0	12	2	0	20	1
50-75 tons	0	0	0	0	0	0	0	0	0
75-100 tons	0	0	0	0	0	0	0	4	0
Dozers									
D4	0	0	0	0	1	0	0	1	0
D5	0	0	0	0	1	0	0	0	0
D6	0	0	0	0	0	0	0	1	0
D7	0	0	0	0	1	0	0	1	0
D8	1	1	1	0	0	0	0	1	0
D9	0	0	0	0	0	0	0	0	0
Draglines									
< 2 cu yd	0	0	0	0	1	0	0	1	0
2-4 cu yd	0	0	0	0	2	0	0	1	0
4-6 cu yd	0	0	0	0	0	0	0	0	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0

(continue Table B.3)

Backhoes									
< 2 cu yd	0	0	0	0	1	0	0	0	2
2-4 cu yd	1	2	1	0	0	0	0	0	1
4-6 cu yd	0	0	0	0	0	0	0	0	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Shovels									
< 2 cu yd	0	0	0	0	0	0	0	0	0
2-4 cu yd	0	0	0	0	0	0	0	0	0
4-6 cu yd	0	0	0	0	0	0	0	0	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Front End Loaders									
< 2 cu yd	0	0	0	0	1	0	0	1	0
2-4 cu yd	0	1	0	0	1	0	0	3	1
4-6 cu yd	0	1	0	0	1	0	0	6	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0

(continue Table B.3)

Twin Pump									
6 x 8"	0	0	0	0	0	0	0	3	1
8 x 10"	0	0	0	0	1	0	0	2	0
10 x 12"	0	0	0	0	0	0	0	1	0
12 x 14"	0	0	0	0	1	0	0	2	0
14 x 16"	0	0	0	0	0	0	0	0	0
16 x 18"	0	0	0	0	0	0	0	2	0
18 x 20"	0	0	0	0	0	0	0	0	0
Submersible									
6 x 8"	0	0	0	0	0	0	0	0	0
8 x 10"	0	1	0	0	0	0	0	1	0
10 x 12"	0	0	0	0	0	0	0	0	0
12 x 14"	0	0	0	0	0	0	0	1	0
14 x 16"	0	0	0	0	0	0	0	0	0
16 x 18"	0	0	0	0	0	0	0	1	0
18 x 20"	0	0	0	0	0	0	0	0	0
Shipment %									
-10 miles	0	20	7	0	65	22	0	50	6
10-20 miles	0	35	20	0	100	53	0	80	18
20-30 miles	0	20	7	0	50	12	0	75	6
30-50 miles	25	98	66	0	15	3	0	100	16
50-75 miles	0	2	1	0	0	0	0	100	18
75-100 miles	0	0	0	0	0	0	0	100	18
100 + miles	0	0	0	0	0	0	0	100	8
Reclamation Costs per acre in thous of $	0.2-0.5	0.5-1	5	0.5-1	3+	1.5-2	0.2-0.5	2-3	1-1.5

Table B.4 **Maximum, Minimum, and Average Response by District - Mississippi**

Question	District 1			District 2			District 3		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
% of Aggregate	0-10	60+	30-40	30-40	60+	40-50	0-10	60+	30-40
Depth of Mining	-20′	80′+	20-30′	30-40′	70-80′	40-50′	-20′	80′+	40-50′
Depth of Overburden	2-4′	25′	6-8′	2-4′	25′	10-20′	0-2′	25′	8-10′
Overburden Removal	Strip	Proc	Strip	Strip	Strip	Strip	Strip	Proc	Strip
Overburden sold	Yes	No	No	Yes	No	No	Yes	No	No
Remaining Active Reserves (years)	0-5	15-20	5-10	0-5	20-25	5-10	0-5	20-25	5-10
Remaining Inactive Reserves (years)	0-10	30-50	0-10	0-10	30-50	10-20	0-10	10-20	0-10
Acres Mined	0-5	10-15	5-10	0-5	10-15	5-10	0-5	30-40	5-10
Production and Maintenance Personnel	1	23	7	2	22	11	2	34	7
Administrative Personnel	1	250	22	0	5	2	0	5	2
Operating days in a year	1	365	212	208	360	260	240	310	270

(continue Table B.4)

Shift/day	1	8	1	1	1	1	1	1	1
Shift hours	8	10	9	8	10	9	8	12	10
Fuel($)	0	83,500	30,809	4,000	186,000	83,172	7,000	84,292	39,061
Electricity	0	100,000	23,588	0	144,000	30,189	0	100,000	23,330
# of Trucks	1	11	3	1	5	2	0	13	3
Haulage Units									
< 25 tons	0	4	1	0	2	1	0	1	0
25-50 tons	0	4	1	0	9	2	0	1	0
50-75 tons	0	0	0	0	0	0	0	0	0
75-100 tons	0	0	0	0	0	0	0	0	0
Dozers									
D4	0	1	0	0	1	0	0	1	0
D5	0	1	0	0	1	0	0	1	0
D6	0	1	0	0	1	0	0	3	1
D7	0	1	0	0	5	1	0	1	0
D8	0	2	0	0	1	0	0	1	0
D9	0	2	0	0	0	0	0	0	0
Draglines									
< 2 cu yd	0	1	0	0	3	0	0	3	1
2-4 cu yd	0	1	0	0	1	0	0	0	0
4-6 cu yd	0	0	0	0	0	0	0	0	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0

(continue Table B.4)

Backhoes									
< 2 cu yd	0	1	0	0	1	0	0	1	0
2-4 cu yd	0	2	0	0	1	0	0	1	0
4-6 cu yd	0	1	0	0	0	0	0	0	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Shovels									
< 2 cu yd	0	1	0	0	0	0	0	0	0
2-4 cu yd	0	0	0	0	0	0	0	0	0
4-6 cu yd	0	0	0	0	0	0	0	0	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Front End Loaders									
< 2 cu yd	0	0	0	0	3	1	0	0	0
2-4 cu yd	0	3	1	0	5	1	0	2	1
4-6 cu yd	0	3	1	0	3	1	0	5	1
6-8 cu yd	0	3	0	0	1	0	0	1	0
8-10 cu yd	0	0	0	0	2	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0

(continue Table B.4)

Twin Pump									
6 x 8"	0	1	0	0	2	0	0	1	0
8 x 10"	0	2	0	0	1	0	0	2	1
10 x 12"	0	1	0	0	1	0	0	1	0
12 x 14"	0	0	0	0	0	0	0	2	0
14 x 16"	0	0	0	0	0	0	0	0	0
16 x 18"	0	0	0	0	0	0	0	0	0
18 x 20"	0	0	0	0	0	0	0	0	0
Submersible									
6 x 8"	0	1	0	0	0	0	0	1	0
8 x 10"	0	0	0	0	0	0	0	1	0
10 x 12"	0	0	0	0	0	0	0	2	0
12 x 14"	0	0	0	0	0	0	0	2	0
14 x 16"	0	0	0	0	0	0	0	0	0
16 x 18"	0	0	0	0	0	0	0	0	0
18 x 20"	0	0	0	0	0	0	0	0	0
Shipment %									
-10 miles	0	80	20	0	80	20	0	30	9
10-20 miles	0	100	43	0	60	21	0	60	17
20-30 miles	0	60	20	0	100	38	0	100	22
30-50 miles	0	50	13	0	95	19	0	80	25
50-75 miles	0	20	4	0	15	2	0	55	10
75-100 miles	0	5	0	0	5	1	0	75	9
100 + miles	0	0	0	0	0	0	0	60	7
Reclamation Costs per acre in thous of $	0.2-0.5	3+	0.5-1	0.2-0.5	1.5-2.0	0.5-1	0.2-0.5	1.5-2.0	0.5-1

Table B.5 **Maximum, Minimum, and Average Response by District - Texas**

Question	District 1			District 2			District 3		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
% of Aggregate	50-60	60+	50-60	40-50	60+	50-60	30-40	30-40	30-40
Depth of Mining	-20′	30-40′	20-30′	-20′	30-40′	20-30′	30-40′	20-30′	-20′
Depth of Overburden	2-4′	10-15′	6-8′	6-8′	15-20′	8-10′	0-2′	8-10′	2-4′
Overburden Removal	Strip	Strip	Strip	Strip	Strip	Strip	Strip	Proc	Strip
Overburden sold	No	No	No	No	No	No	No	No	No
Remaining Active Reserves (years)	5-10	10-15	10-15	0-5	20-25	5-10	0-5	20-25	10-15
Remaining Inactive Reserves (years)	0-10	10-20	10-20	0-10	20-30	10-20	.	.	.
Acres Mined	5-10	30-40	15-20	5-10	20-30	15-20	0-5	5-10	0-5
Production and Maintenance Personnel	5	18	12	4	18	10	1	10	5
Administrative Personnel	2	4	3	1	3	2	1	2	1
Operating days in a year	200	200	200	210	253	233	40	300	170

(continue Table B.5)

Shift/day	1	1	1	1	1	1	1	2	1
Shift hours	9	10	9	8	11	10	8	8	8
Fuel($)	50,000	14,0000	95,000	15,000	180,000	78,250	2,000	8,4000	4,3000
Electricity	36,000	60,000	48,000	600	137,000	54,712	1,000	1,000	1,000
# of Trucks	2	3	3	0	4	2	1	2	1
Haulage units									
< 25 tons	1	6	4	0	4	1	0	2	1
25-50 tons	0	0	0	0	3	1	0	0	0
50-75 tons	0	0	0	0	0	0	0	0	0
75-100 tons	0	0	0	0	0	0	0	0	0
Dozers									
D4	0	0	0	0	0	0	0	0	0
D5	0	0	0	0	0	0	0	0	0
D6	0	0	0	0	2	1	0	1	0
D7	0	2	1	0	0	0	0	0	0
D8	0	0	0	0	1	0	0	1	0
D9	0	0	0	0	0	0	0	0	0
Draglines									
< 2 cu yd	0	0	0	0	1	0	0	0	0
2-4 cu yd	0	0	0	0	2	0	0	0	0
4-6 cu yd	0	0	0	0	0	0	0	0	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0

(continue Table B.5)

Backhoes									
< 2 cu yd	0	0	0	0	0	0	0	0	0
2-4 cu yd	0	0	0	0	1	0	0	0	0
4-6 cu yd	0	0	0	0	0	0	0	0	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Shovels									
< 2 cu yd	0	0	0	0	0	0	0	0	0
2-4 cu yd	0	0	0	0	0	0	0	0	0
4-6 cu yd	0	0	0	0	0	0	0	0	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Front End Loaders									
< 2 cu yd	0	0	0	0	0	0	0	1	0
2-4 cu yd	0	1	0	0	2	0	0	1	0
4-6 cu yd	2	3	2	0	5	1	0	2	1
6-8 cu yd	0	2	1	0	0	0	0	1	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0

(continue Table B.5)

Twin Pump									
6 x 8"	0	0	0	0	0	0	0	0	0
8 x 10"	0	0	0	0	2	0	0	0	0
10 x 12"	0	0	0	0	1	0	0	0	0
12 x 14"	0	0	0	0	0	0	0	0	0
14 x 16"	0	0	0	0	1	0	0	0	0
16 x 18"	0	0	0	0	0	0	0	0	0
18 x 20"	0	0	0	0	0	0	0	0	0
Submersible									
6 x 8"	0	0	0	0	0	0	0	0	0
8 x 10"	0	0	0	0	0	0	0	0	0
10 x 12"	0	0	0	0	0	0	0	0	0
12 x 14"	0	0	0	0	0	0	0	0	0
14 x 16"	0	0	0	0	0	0	0	0	0
16 x 18"	0	0	0	0	0	0	0	0	0
18 x 20"	0	0	0	0	0	0	0	0	0
Shipment %									
-10 miles	0	40	13	0	98	24	0	75	27
10-20 miles	0	0	0	0	10	2	0	45	17
20-30 miles	0	60	30	0	30	14	10	20	14
30-50 miles	0	80	30	0	60	34	5	30	18
50-75 miles	0	10	7	0	50	15	0	70	23
75-100 miles	10	20	13	0	0	0	0	9	3
100 + miles	0	10	6	0	40	10	0	0	0
Reclamation Costs per acre in thous of $	0.2-0.5	0.5-1	0.2-0.5	0.2-0.5	1-1.5	0.5-1	0.2-0.5	0.2-0.5	0.2-0.5

(continue Table B.5)

Question	District 4			5			6		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
% of Aggregate	40-50	60+	50-60	0-10	60+	30-40	0-10	60+	30-40
Depth of Mining	-20'	30-40'	20-30'	-20'	70-80'	30-40'	30-40'	-20'	20-30'
Depth of Overburden	0-2'	6-8'	2-4'	0-2'	25'+	8-10'	0-2'	0-2'	0-2'
Overburden Removal	Strip	Stip	Strip	Strip	Strip	Strip	Strip	Strip	Strip
Overburden sold	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Remaining Active Reserves (years)	0-5	15-20	5-10	0-5	20-25	5-10	5-10	15-20	10-15
Remaining Inactive Reserves (years)	0-10	0-10	0-10	0-10	20-30	10-20	10-20	10-20	10-20
Acres Mined	0-5	10-15	5-10	0-5	70-80	15-20	0-5	30-40	10-15
Production and Maintenance Personnel	3	8	5	0	33	10	2	5	3
Administrative Personnel	2	2	2	0	3	2	3	3	3

(continue Table B.5)

Operating days in a year	189	240	214	80	280	215	24	264	144
Shift/day	1	1	1	1	2	1	1	1	1
Shift hours	10	10	10	4	10	9	8	10	9
Fuel($)	24,000	30,611	27,305	1,150	218,400	75,300	1,200	16,300	8,750
Electricity	14,819	19,200	17,009	0	480,000	72,803	0	16,122	8,061
# of Trucks	1	3	2	0	12	4	0	3	1
Haulage units									
< 25 tons	2	3	3	0	1	0	0	0	0
25-50 tons	0	0	0	0	15	3	2	2	2
50-75 tons	0	0	0	0	12	1	0	0	0
75-100 tons	0	0	0	0	0	0	0	0	0
Dozers									
D4	0	1	0	0	1	0	0	0	0
D5	0	0	0	0	3	0	0	0	0
D6	0	1	0	0	2	0	0	0	0
D7	0	1	0	0	1	0	1	1	1
D8	0	0	0	0	1	0	0	0	0
D9	0	0	0	0	1	0	0	0	0

(continue Table B.5)

Draglines									
< 2 cu yd	0	2	1	0	1	0	0	1	0
2-4 cu yd	0	0	0	0	1	0	0	0	0
4-6 cu yd	0	2	1	0	3	1	0	0	0
6-8 cu yd	0	0	0	0	2	0	0	0	0
8-10 cu yd	0	0	0	0	2	0	0	0	0
10+ cu yd	0	0	0	0	1	0	0	0	0
Backhoes									
< 2 cu yd	0	1	0	0	1	0	0	0	0
2-4 cu yd	0	0	0	0	0	0	0	1	0
4-6 cu yd	0	0	0	0	1	0	0	0	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Shovels									
< 2 cu yd	0	0	0	0	0	0	0	0	0
2-4 cu yd	0	0	0	0	0	0	0	0	0
4-6 cu yd	0	2	1	0	0	0	0	0	0
6-8 cu yd	0	0	0	0	1	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0

(continue Table B.5)

Front End Loaders									
< 2 cu yd	0	0	0	0	0	0	0	0	0
2-4 cu yd	2	2	2	0	2	1	1	3	2
4-6 cu yd	0	1	1	0	4	1	0	0	0
6-8 cu yd	0	0	0	0	4	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Twin Pump									
6 x 8"	0	0	0	0	0	0	0	1	0
8 x 10"	0	0	0	0	2	0	0	0	0
10 x 12"	0	0	0	0	0	0	0	0	0
12 x 14"	0	0	0	0	0	0	0	0	0
14 x 16"	0	0	0	0	0	0	0	0	0
16 x 18"	0	0	0	0	0	0	0	0	0
18 x 20"	0	0	0	0	0	0	0	0	0
Submersible									
6 x 8"	0	0	0	0	0	0	0	0	0
8 x 10"	0	0	0	0	0	0	0	0	0
10 x 12"	0	0	0	0	0	0	0	0	0
12 x 14"	0	0	0	0	0	0	0	0	0
14 x 16"	0	0	0	0	0	0	0	0	0
16 x 18"	0	0	0	0	0	0	0	0	0
18 x 20"	0	0	0	0	0	0	0	0	0

(continue Table B.5)

Shipment %									
-10 miles	0	50	23	0	100	30	0	90	45
10-20 miles	0	30	13	0	25	9	0	5	2
20-30 miles	0	20	10	0	100	17	0	5	2
30-50 miles	10	98	43	0	90	29	0	0	0
50-75 miles	0	10	7	0	60	13	0	0	0
75-100 miles	0	0	0	0	10	1	0	0	0
100 + miles	0	0	0	0	10	1	0	75	37
Reclamation Costs per acre in thous of $	0.2-0.5	1.5-2	0.5-1	0.2-0.5	2-3	0.5-1	0.2-0.5	0.5-1	0.2-05

Question	District 7			District 8			District 9		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
% of Aggregate	10-20	60+	50-60	0-10	50-60	20-30	0-10	60+	30-40
Depth of Mining	-20′	70-80′	30-40′	-20	50-60	20-30	-20	-20	-20
Depth of Overburden	0-2′	2-4′	6-8′	0-2′	25′	6-8′	0-2′	4-6′	2-4′
Overburden Removal	Strip	Proc	Strip	Strip	Proc	Strip	Strip	Strip	Strip
Overburden sold	Yes	No	No	Yes	No	Yes	Yes	No	Yes
Remaining Active Reserves (years)	0-5	20-25	5-10	0-5	20-25	10-15	0-5	5-10	0-5

(continue Table B.5)

Remaining Inactive Reserves (years)	0-10	30-40	10-15	0-10	30-50	10-20	0-10	0-10	0-10
Acres Mined	0-5	15-20	5-10	0-10	50-60	10-25	10-15	50-60	20-30
Production and Maintenance Personnel	2	25	11	2	69	11	3	6	5
Administrative Personnel	1	4	2	0	6	2	1	2	1
Operating days in a year	100	365	262	183	272	234	250	275	262
Shift/day	1	2	1	1	3	1	1	2	1
Shift hours	8	12	10	8	12	9	9	10	10
Fuel($)	3,000	158,000	73,225	0	119,040	41,005	39,600	48,104	43852
Electricity	0	225,000	40,330	0	276,000	56,800	2,501	27,600	15050
# of Trucks	0	4	3	0	8	3	1	3	2
Haulage units									
< 25 tons	0	14	3	0	13	3	0	1	1
25-50 tons	0	8	2	0	18	4	0	2	1
50-75 tons	0	1	0	0	0	0	0	0	0
75-100 tons	0	3	0	0	0	0	0	0	0

(continue Table B.5)

Dozers									
D4	0	1	0	0	2	1	0	0	0
D5	0	0	0	0	0	0	0	0	0
D6	0	1	0	0	2	0	0	1	1
D7	0	1	0	0	2	0	0	1	1
D8	0	1	0	0	0	0	0	0	0
D9	0	0	0	0	0	0	0	0	0
Draglines									
< 2 cu yd	0	1	0	0	5	1	0	0	0
2-4 cu yd	0	1	0	0	4	0	0	0	0
4-6 cu yd	0	0	0	0	1	0	0	0	0
6-8 cu yd	0	1	0	0	0	0	0	0	0
8-10 cu yd	0	1	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Backhoes									
< 2 cu yd	0	0	0	0	2	0	0	1	0
2-4 cu yd	0	2	0	0	2	0	0	0	0
4-6 cu yd	0	0	0	0	0	0	0	0	0
6-8 cu yd	0	1	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Shovels									
< 2 cu yd	0	0	0	0	0	0	0	0	0
2-4 cu yd	0	0	0	0	3	0	0	0	0
4-6 cu yd	0	0	0	0	2	0	0	0	0
6-8 cu yd	0	0	0	0	0	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0

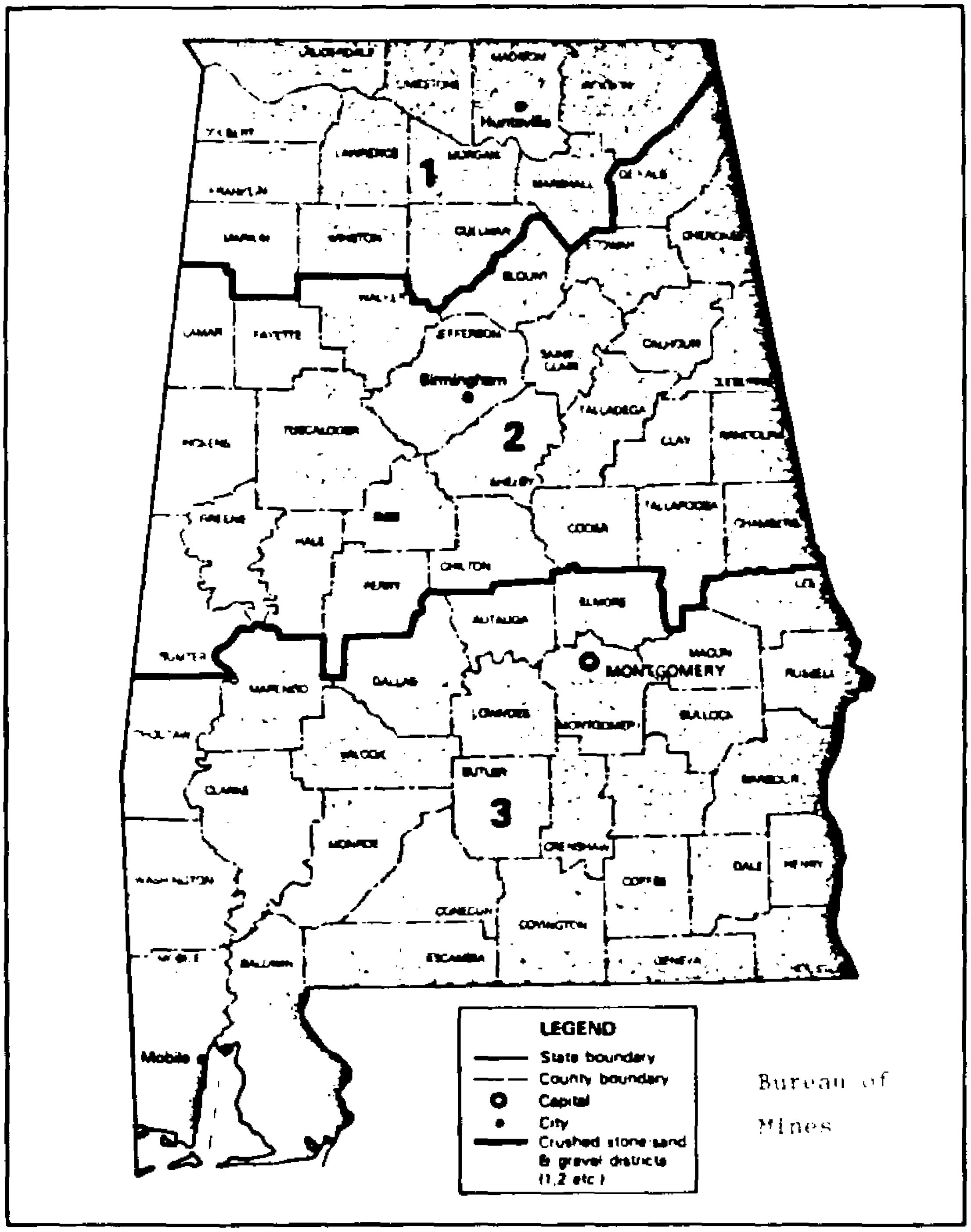
(continue Table B.5)

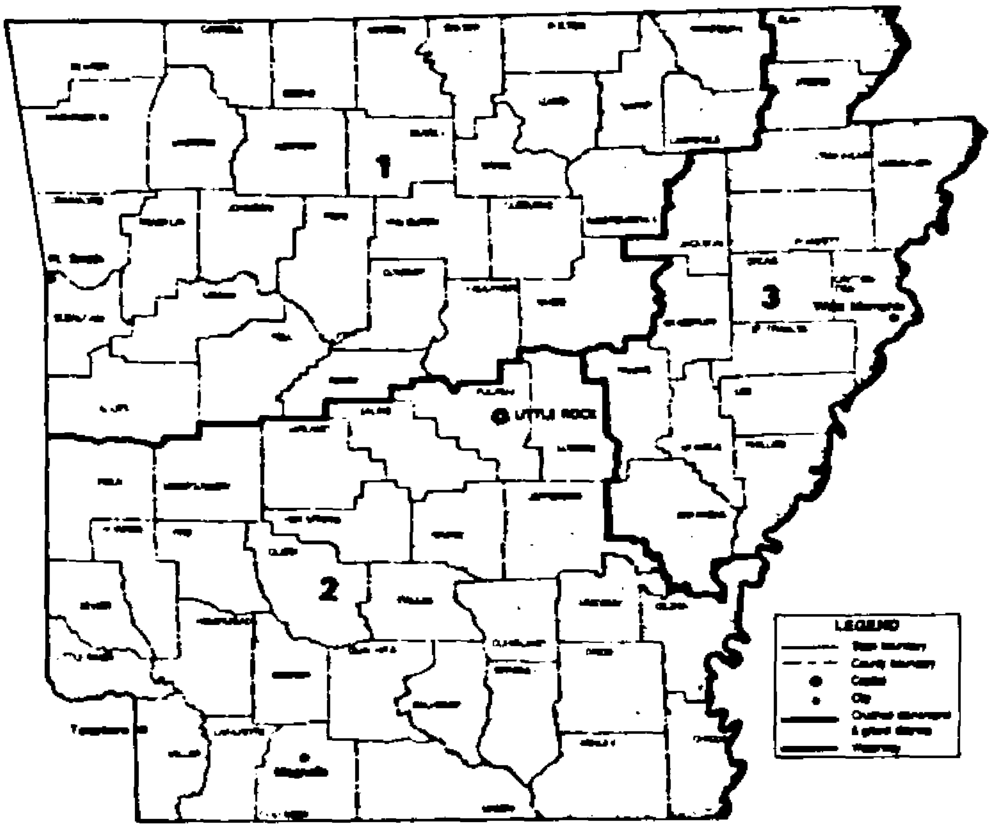
Front End Loaders									
< 2 cu yd	0	1	0	0	1	0	0	1	0
2-4 cu yd	0	3	1	0	2	0	0	2	1
4-6 cu yd	0	3	1	0	3	1	0	0	0
6-8 cu yd	0	2	0	0	4	0	0	0	0
8-10 cu yd	0	0	0	0	0	0	0	0	0
10+ cu yd	0	0	0	0	0	0	0	0	0
Twin Pump									
6 x 8"	0	1	0	0	1	0	0	0	0
8 x 10"	0	1	0	0	1	0	0	0	0
10 x 12"	0	0	0	0	1	0	0	0	0
12 x 14"	0	0	0	0	1	0	0	0	0
14 x 16"	0	0	0	0	0	0	0	0	0
16 x 18"	0	0	0	0	0	0	0	0	0
18 x 20"	0	0	0	0	0	0	0	0	0
Submersible									
6 x 8"	0	1	0	0	2	0	0	0	0
8 x 10"	0	0	0	0	1	0	0	0	0
10 x 12"	0	0	0	0	1	0	0	0	0
12 x 14"	0	0	0	0	0	0	0	0	0
14 x 16"	0	0	0	0	0	0	0	0	0
16 x 18"	0	0	0	0	0	0	0	0	0
18 x 20"	0	0	0	0	0	0	0	0	0

(continue Table B.5)

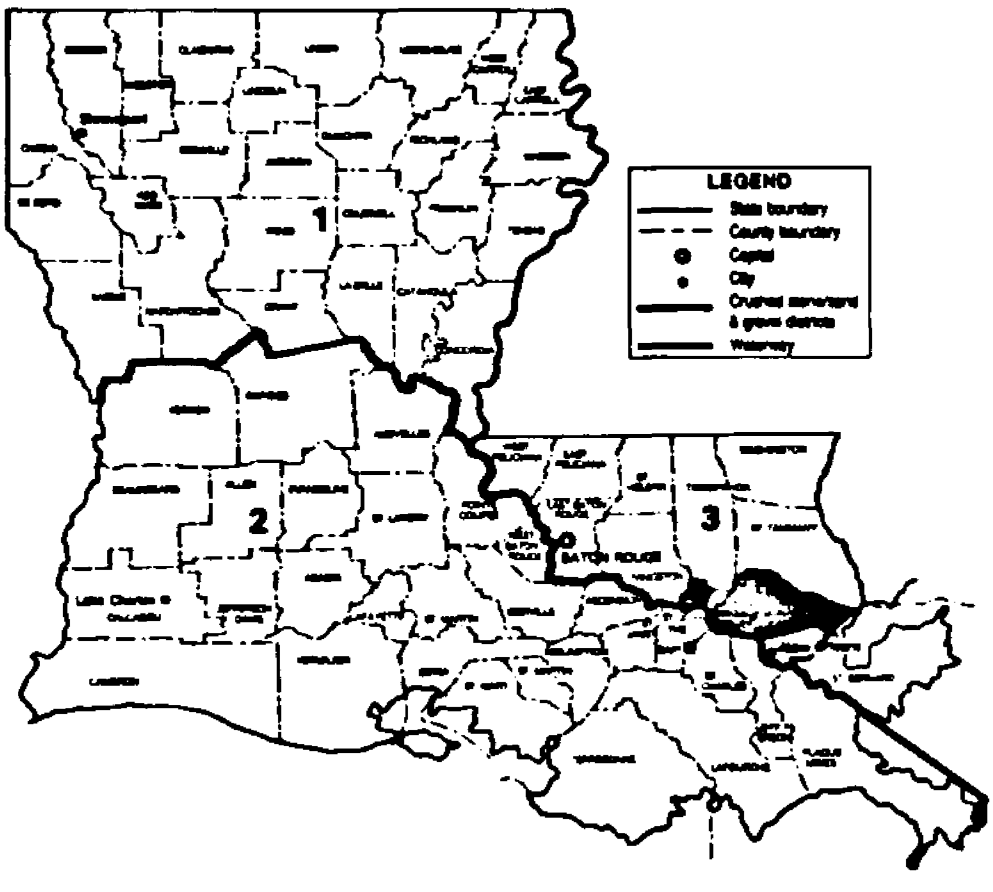
Shipment %									
-10 miles	0	100	43	0	50	10	0	75	25
10-20 miles	0	30	13	0	85	22	0	100	40
20-30 miles	0	70	23	0	90	19	0	5	2
30-50 miles	0	50	9	0	30	5	0	0	0
50-75 miles	0	10	2	0	100	27	0	100	33
75-100 miles	0	20	2	0	80	8	0	0	0
100 + miles	0	60	6	0	25	3	0	0	0
Reclamation Costs per acre in thous of $	0.20-0.5	3+	0.5-1	0.2-0.5	2-3	0.5-1	0.2-0.5	2-3	1-1.5

APPENDIX C

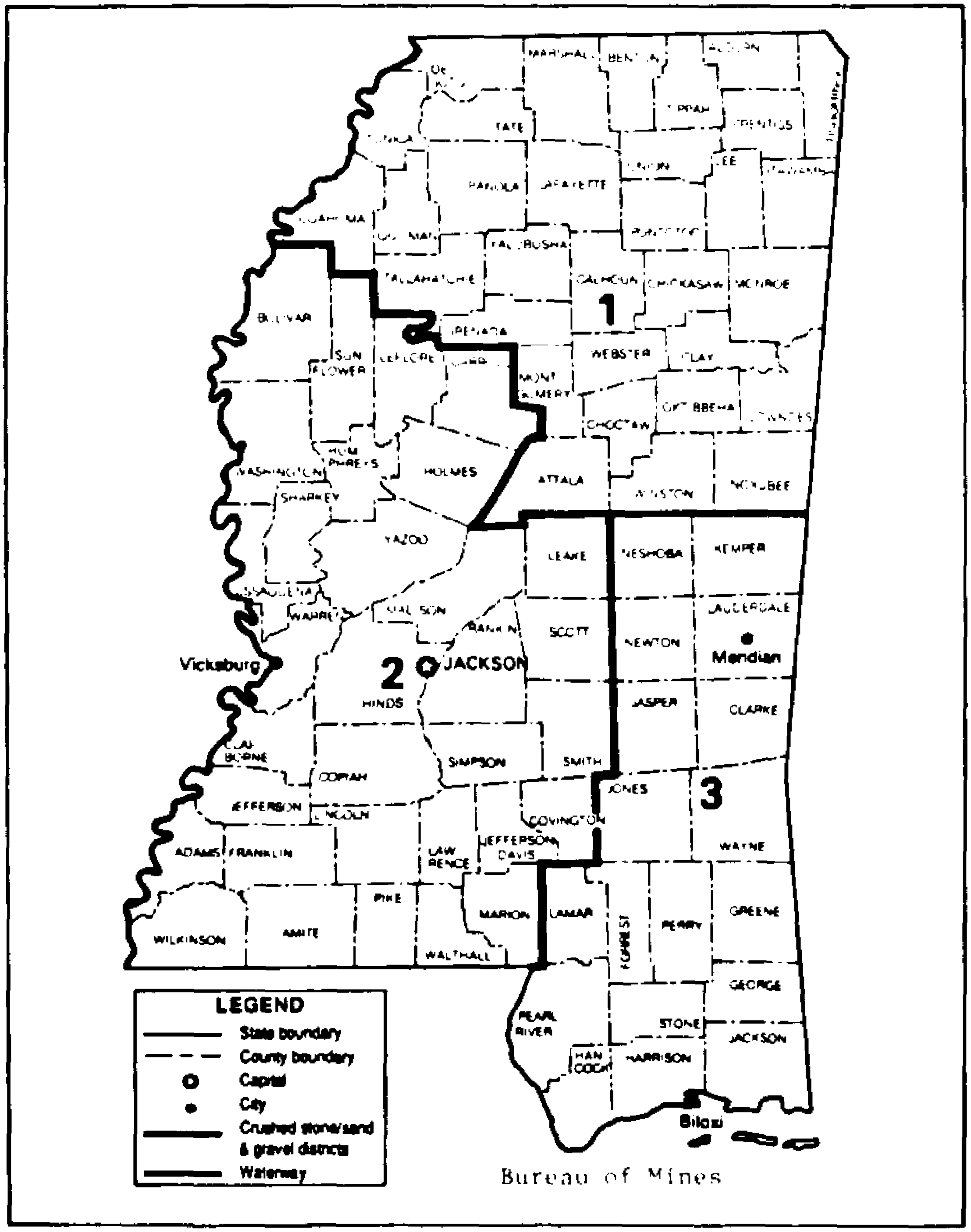

Huntsville
1
Birmingham
2
MONTGOMERY
3
Mobile
LEGEND
State boundary
County boundary
Capital
City
Crushed stone-sand & gravel districts (1,2 etc.)
Bureau of Mines



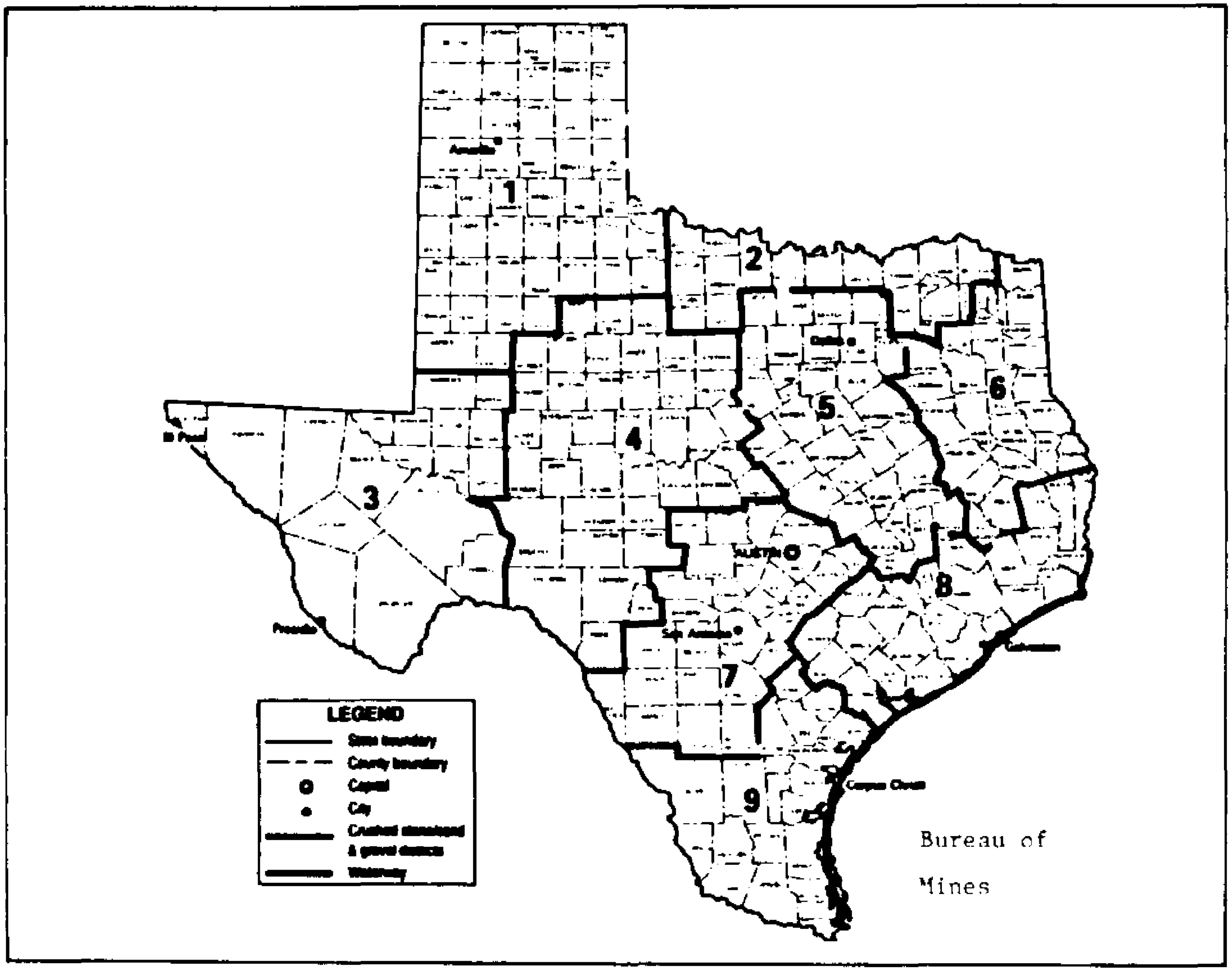
Bureau of Mines



Bureau of Mines



Bureau of Mines


1
2
3
4
5
6
7
8
9
LEGEND
Bureau of
Mines

VITA

Alicia N. Rambaldi was born in Córdoba, Argentina, January 6, 1959. She graduated from the "Universidad Nacional de Córdoba" with a Bachelors' Degree in "Ingeniería Agronómica" in October 1982. She accepted a trainee position at the "Instituto Nacional de Tecnología Agropecuaria-Estación Experimental Reconquista" in the Santa Fe province, Argentina in March 1983, and one year later she joined the faculty of the "Universidad Nacional de Córdoba, Facultad de Ciencias Agropecuarias, Departamento de Economía Agraria y Extensión Rural" as a Senior Teaching Assistant.

In December 1988 she graduated from Louisiana State University with a Masters' Degree in Agricultural Economics. During her program, she was a recipient of a Fulbright Scholarship.

The author entered the Ph.D program in Agricultural Economics at Purdue University in January 1989. She transferred to the Ph.D program in Economics at Louisiana State University in January 1990.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Alicia Norma Rambaldi

Major Field: Economics

Title of Dissertation: A Regional Market Model for Construction Aggregate Materials

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

07/14/92