MARKET FAILURE IN MULTIPHASE ELECTRIC POWER DEVELOPMENT FOR AGRICULTURAL IRRIGATION

Bernard V. Tew, Josef M. Broder, Wesley N. Musser, and Terence J. Centner

Abstract

The adoption of multiphase electric power for electric irrigation has been limited in an area characterized by extremely rapid expansion of irrigated acreage despite production cost advantages. Theoretical and empirical evidence of failure in the existing market for multiphase power development are presented. Alternative development mechanisms are presented and discussed.

Key words: multiphase power development, market failure, irrigation, energy.

Recent instabilities in energy supplies and prices have generated a need for energy related research in agriculture. In recent years, agricultural scientists have studied energy needs and efficiency in food production (Debertin and Pagoulatos; Tyner; Holland), food processing (Broder and Booth; Jones and Lee) and alternative energy sources (Webb; Hertzmark et al.). In general, these studies approached agricultural energy as a private or incompatible use good which has low exclusion costs and is readily allocated through market mechanisms. Using a market framework, these studies have predicted the impacts of energy policies and price changes on food production, processing, and consumption.

Largely ignored by previous studies is the public goods dimension of agricultural energy inputs which necessitates some type of public or collective choice. When production or consumption of a particular energy source requires collective effort, conventional market mechanisms are often inadequate for allocating such energy supplies. When such market failure exists, non-market alternatives can be used to allocate energy resources.

A particular area of agricultural energy with public goods dimensions is the development of multiphase (three-phase) electric power and its use for agricultural irrigation. Although single phase power is adequately distributed in rural Georgia by electric membership cooperatives (EMC's), multiphase power is necessary for the large horsepower electric motors that are required by most irrigation systems.[1] While multiphase electricity is more efficient than diesel fuel in irrigation, its development and use has been limited despite these cost advantages. The objectives of this paper are to: (1) examine patterns of multiphase electric power consumption in Georgia, (2) examine evidence of market failure in existing markets for multiphase power development, (3) estimate production efficiency losses from market failure, and (4) discuss non-market

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[1] Recently, mechanical multiphase converters have been developed which allow some substitution of single phase for multiphase power. The cost of these converters is highly variable and depends on the specific application. The initial purchase cost range of $5,000 to $20,000 is below average multiphase line construction costs and may potentially reduce the demand for multiphase power development by some remote or isolated consumers. However, use of these converters involves other costs which have discouraged their adoption. Specifically, a separate converter must be purchased for each new application and the user is responsible for maintaining and servicing these converters. Hence, for large diversified operations, the development of multiphase power is thought to be economically superior to these converters in the long run.

alternatives for developing multiphase power for agricultural irrigation.

THEORETICAL FRAMEWORK

Multiphase electric power development can be analyzed in a public goods framework. The two key elements of a pure public good include nonrivalry and nonexclusiveness in consumption (Randall). Nonrivalry results when the marginal cost of an additional user of a public good is zero or when the good is joint impact in nature (Schmid). Nonexclusiveness or high exclusion costs result when exclusion of potential customers is not feasible (Musgrave; Samuelson). The use of the term "public" refers only to the nature of consumption and does not prescribe the nature of the producer (Bish).

Multiphase electric power development is characterized by both nonrivalry and nonexclusiveness. Nonrivalry refers to the relationship between users when an additional multiphase power user is connected to an existing multiphase line. Once the lines are constructed, an additional user has little effect on the availability of power to other customers. Hence, nonrivalry is embodied in the physical properties of the good (multiphase power) and its method of distribution (power lines).

The nonexclusive properties of multiphase power derive more from the legal environment rather than the physical properties of the good. State statutes prohibit EMC's from charging differential rates to agricultural customers along a multiphase power line, regardless of differences in customer contributions to initial development costs. Once a line is built, new multiphase power users need only pay the marginal costs of bringing the power from existing multiphase lines to their farms. After these marginal costs are paid, exclusion of multiphase power customers who have not contributed to the costs of developing the initial or trunk multiphase lines is not possible.

The nonrivalry and nonexclusive nature of public goods creates special problems for allocating resources to public goods. These problems are best illustrated by comparing the allocative process between public and private goods. The optimal level of consumption of both public and private goods is achieved where the marginal cost is equal to the individual consumer's marginal benefit. For private goods characterized by low exclusion and rivalry in consumption, a consumer simply purchases additional amounts until an optimum is achieved.

For public goods, if one individual voluntarily provides the good, others may enjoy the good without payment or for a nominal fee. Initial customers create positive externalities for future customers who cannot be excluded from consumption. Voluntary contributions from these subsequent consumers are uncertain since some consumers underestimate their true demands for the good in hopes of enjoying the good without payment or for a nominal fee. Unless collective activity is successful in extracting the appropriate payment from each customer, the level of the public good provided by the group as a whole is likely to be below the optimal level. The underprovision of public goods by private market mechanisms is herein referred to as "market failure."

Figure 1 illustrates the optimal level and marginal prices of multiphase power development with public good characteristics (Bish, p. 29). The demand schedules D_1, D_2, and D_3 illustrate the demand for multiphase power by three different individuals. The demand schedule PG is a vertical summation of the individual demand curves and represents aggregate demand for the public good.

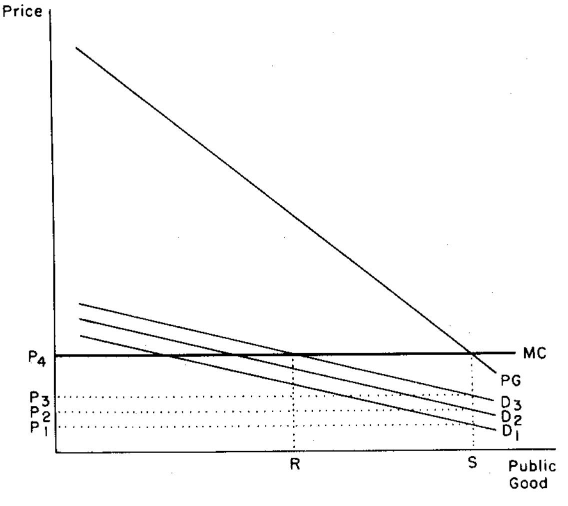

Figure 1. Multiphase Power Line Construction as a Public Good.

A vertical instead of a horizontal summation is appropriate for a public good because the summed demand represents the total amount all three consumers are willing to pay to obtain a particular output which is available to all potential users. For example, the third consumer is willing to obtain output R at price P_4 for his use. However, at that price the first and second consumers may consume R output without payment. If transactions costs are zero, the three consumers could achieve net gains by providing output S through collective activity. At S, the sum of their marginal evaluations is equal to the marginal cost. The first consumer contributes P_1 to the cost of an additional unit of output at level S and some amount less than his total benefits (the area under his demand curve up to S). In the presence of transactions costs, uncertainties and strategic bargaining over the financing of the intramarginal units, private markets may fail to provide the optimal level of the public good.

The example given illustrates that the effectiveness of collective economic activity in providing an optimal level of a public good is influenced by transactions costs. In a world of imperfect knowledge, transactions costs take the form of information, contractural, and policing costs (Rogers; Dahlman). Identifying and informing potential beneficiaries of collective action and measuring individual demands involve information costs. Reaching a collective agreement and making some collective bid involve contractural costs while protecting the assets of collective action involves policing costs. When transaction costs exceed the potential gains from collective action, such action may not be forthcoming or it may be less than optimal (Dahlman).

Empirical research on transactions costs is limited due to the non-market and non-monetary components of such costs. Factors which influence transactions costs and the ability for groups to act collectively include: (1) group size, (2) the degree of member participation (Buchanan and Tullock), (3) distribution of member preferences (Kafoglis and Cebula), (4) personal and group wealth, (5) potential gains from group participation, and (6) sense of community (Schmid).

Relationships between the above characteristics and transactions costs will not be fully explored in this research. Instead, the absence of collective action in the development of multiphase power will be presented as evidence that: (1) transactions costs exceed the benefits of collective action, (2) private markets for multiphase power development have failed, and (3) multiphase power development may require supplementing private market mechanisms.

The concept of market failure used herein is descriptive rather than prescriptive in nature. In other words, the existence of market failure is not sufficient evidence that a non-market alternative is either superior or desirable. The choice of institutional arrangements for multiphase power development must take into account the positive and negative distributional consequences of market supplements. These market supplements and their distributional consequences are addressed in this paper.

DATA

The data used in this analysis were obtained from a survey of EMC's in Georgia. Georgia has 42 EMC's which serve in excess of 72 percent of the land area in the State and over two million customers. The survey was mailed to the operating manager of each cooperative in September 1981. Fifty-two percent or 22 of the surveys were completed and returned. The responding cooperatives represented every region of the State including metropolitan, rural agricultural, and rural non-agricultural areas. However, the respondents were concentrated in the southeast and southwest portions of the State. This area includes the dominant agricultural and irrigation areas of the State. The majority of nonresponses were in urban areas or nonagricultural areas. Thus, the problem of nonrespondent bias was thought to be relatively minor in this example. The respondents provide electric service to 338,394 residential, 13,152 industrial, and 21,418 specifically designated agricultural customers. The average cooperative served approximately 17,000 total customers with over 90 percent of these customers classified as residential. A summary of the information obtained from the respondents is included in tables 1 and 2.

Information was also obtained in the survey on interruptible power service, which is a relatively new option service for Georgia electric companies. This option allows a power company to temporarily disconnect service during a peak use load; the most common contractural interruptible period in Georgia is between 4:00 p.m. and 8:00 p.m.

TABLE 1. MULTIPHASE USERS OF ELECTRIC MEMBERSHIP COOPERATIVES, GEORGIA, 1981

Item	Customers		
	Residential	Industrial	Agricultural
	.... Number		
EMC's offering multiphase power	—	22	22
Multiphase customers	—	2,221	266
EMC's offering interruptible service[a]	3	0	8

[a]The most common time for interrupted service was from 4:00 p.m. - 8:00 p.m.

In exchange for this potential peak load interruption, the user receives a discount on all power. Discounts available on this type of service averaged 38 percent with a range of 60 percent to no discount. Since this option could be used in most irrigation situations, its potential is analyzed in this paper.

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All of the respondents offered multiphase power with a total of 2,221 industrial and 266 agricultural customers reported in the survey. A parent organization provides the construction service of multiphase line for all of the EMC's in Georgia. Construction costs, a limiting factor in multiphase development, averaged $16,235 per mile although the range of these costs was from $6,000 to $25,000 per mile. Variations in construction costs were attributed to the following factors: (1) difficulty of terrain, (2) limited number of routings, and (3) existing territorial barriers such as county boundaries or city limits.

TABLE 2. DEVELOPMENT COST ON MULTIPHASE LINE AND DISCOUNTS AVAILABLE TO INTERRUPTIBLE POWER USERS OF ELECTRIC MEMBERSHIP COOPERATIVES, GEORGIA, 1981

Item	Average	Range
Development cost on multiphase line		
All customers ($/mile)	16,235	6,000-25,000
Discounts available to interruptible power users[a]		
Residential (percent)	38	0 - 60
Agricultural (percent)	38	0 - 60

[a]The responding EMC's offered some discounts for residential and agricultural customers. No responses were given for industrial customers. There was no consistency among EMC's not charging construction costs and charging higher consumption rates.

Each cooperative reported two aspects of construction costs. First, a total cost per mile paid by the cooperative to the line construction firm was reported. Second, the portion of that cost actually paid by the customer was reported. For example, one cooperative paid $25,000 per mile to the line construction company and a customer of this cooperative paid $25,000 per mile to the cooperative. In contrast, another cooperative also paid $25,000 per mile to the line construction firm while a customer of this cooperative paid only $15,000 per mile to the cooperative for multiphase line installation.

A lower cost cooperative, one that paid $6,800 per mile for line installation, charged its customer the full costs of construction. Other lower cost cooperatives did not charge their customers for multiphase line installation. While some variation in costs of construction would be expected, the variation in charges for multiphase power indicates that some cooperatives may be responding to the externalities and financing the collective aspects of the power development.

While a rigorous analysis of all factors which contribute to market failure will not be attempted, some relationships between the consumer demand for multiphase power development and transactions costs can be inferred from the data.[2] Transactions costs of collective action such as information, organizational, and bargaining costs among current and future users reduce the effective demand of individual or collective action (Rogers). High development costs and high transactions costs were thought to be associated with low effective demand for such development. Hence, the level of multiphase power development in an area should be directly related to the share of the development costs borne by power companies. A Spearman rank correlation coefficient (r_S) between the proportion of development costs assumed by the EMC's and number of multiphase customers was estimated from the sample data.[3] When adjusted for ties, the $r_S = 0.7417$ (with Student's t-statistic = 4.94) was found to be significant at the $\alpha = 0.005$ level. This r_S coefficient supports the view

[2] Other factors which might influence development include but may not be limited to: (1) the number of potential multiphase power customers, (2) the income of these customers, and (3) the economic potential of multiphase power availability. Further research is recommended to document the influence of these and other factors.

[3] The Spearman correlation coefficient gives a statistical indication of the degree of association between two variables. Spearman coefficients take on values of −1 to +1 where a value of −1 means perfect negative association and a value of +1 means perfect positive association. For a further discussion of Spearman coefficients, see Siegal.

that multiphase power has not been developed in areas where customers bear a large proportion of the development costs.

EFFICIENCY GAINS FROM MULTIPHASE POWER

The impact of market failure in multiphase power development can be analyzed by estimating efficiency gains from substituting multiphase power for diesel fuel in agricultural irrigation cost estimates. For this analysis, 50-, 100-, 150-, and 200-acre center pivot systems were considered. Currently, more than 91 percent of these systems are diesel powered (Skinner 1982a and 1982b). The Oklahoma State Irrigation Cost Program (Kletke et al.) was utilized to calculate operating costs for the systems. A break-even length of multiphase power line was calculated for each system with the following equation:

$$(1)\ \text{BED} = \frac{\text{TCE} - \text{TCD}}{\text{MDC/mile}},$$

where:

BED = break-even distance,
TCE = total annual costs for electricity,
TCD = total annual costs for diesel, and
MDC = multiphase development cost.

The development cost per mile utilized in the analysis was $16,235, which was the average from the survey, Table 2.

Results of this cost analysis are summarized in Table 3. Total system investment ranges from $56,468 for a 50-acre electric system to $90,504 for a 200-acre diesel system. Potential savings of $2,787 per year for a 50-acre system, $3,972 per year for a 100-acre system, $5,490 for a 150-acre system, and $8,026 for a 200-acre system are available for electric power users without an interruptible service option. The annual savings range from $3,059 to $8,770 using an interruptible service option. With these savings, producers could finance construction of 1.2 miles of multiphase line for a 50-acre system and 1.7 miles of line for a 100-acre system. A producer with a 150-acre electric system could finance construction of 2.6 miles of multiphase line without an interruptible service option and 2.8 miles of line with such an option. A producer with a 200-acre electric system could finance construction of 3.5 miles of multiphase line without an interruptible service option and 3.8 miles of line with such an option. If the capital investment were amortized over a longer period than 7 years, annual capital requirements would be lowered and the breakeven distances in Table 3 would increase.

Figure 2 presents a hypothetical situation for potential users of multiphase power as irrigators. Three fields that are topographically suited for center pivot type irrigation form the basic scenario for this example. Each field is owned by a different individual and all fields are served by an EMC that offers interruptible service and charges customers $16,235 per mile for multiphase line construction. A multiphase line currently exists 6.6 miles from a connection point to field A, 4.4 miles from a similar point for field B, and 4.3 miles from field C. These distances were arbitrarily chosen for the simplicity of subsequent calculations. Fields A and C are 200-acre fields while field B is a 150-acre field. Individual construction costs of multiphase power for fields A, B, and C are respectively: $107,151; $71,434; and $69,810. The location of each field with respect to the existing power lines prohibits further electrical development since ownership of the fields is partitioned among three individuals and the location of each field exceeds the breakeven distances calculated in Table 2. In the absence of subsidies by the EMC or collective action by the farmers, the only viable option for those farmers desiring irrigation is a diesel powered system.

The absence of development is inefficient for the three fields as a whole. For example, the total mileage of lines required to serve all three fields in Figure 2 is only 8.1 miles. The total breakeven mileage for the three fields without interruptible service is 7.4 miles. Potentially, if each of these individuals were irrigating using electric power, $21,542 in total annual savings would result.[4] Furthermore, through collective action these annual savings less transaction costs would finance the entire line construction expense in 2 years.

The potential savings through collective action must be contrasted to the transactions

[4] A total annual savings of $21,542 results for the farmers in this hypothetical example by summing the appropriate values in Table 2. For example, annual savings for an electrically irrigated 150-acre field is $5,470 and similar savings of $8,026 would be realized for each 200-acre field.

TABLE 3. TOTAL ANNUAL OPERATING COST FOR ELECTRIC AND DIESEL CENTER PIVOT IRRIGATION SYSTEMS INCLUDING AN INTERRUPTIBLE SERVICE OPTION IN GEORGIA, 1981.

Item	Field size and system type							
	50-acre		100-acre		150-acre		200-acre	
	Electric	Diesel	Electric	Diesel	Electric	Diesel	Electric	Diesel
	dollars							
System cost	56,468	61,602	75,308	82,469	77,145	84,158	82,645	90,504
Electric intrafield dev.	1,104	—	1,766	—	2,537	—	2,933	—
Total field investment[a]	57,572	61,602	77,074	82,469	79,682	84,158	85,578	90,504
Annual fixed costs[b]	6,906	7,389	9,314	9,965	9,561	10,099	10,269	10,860
Annual variable costs[c]	—	4,639	—	7,176	—	9,967	—	13,632
With interruption	2,063	—	3,314	—	4,430	—	5,453	—
Without interruption	2,335	—	3,855	—	5,015	—	6,197	—
Total annual costs	—	12,028	—	17,141	—	20,066	—	24,492
With interruption	8,969	—	12,628	—	13,991	—	15,722	—
Without interruption	9,241	—	13,169	—	14,576	—	16,466	—
Annual savings								
With interruption	3,059	—	4,513	—	6,075	—	8,770	—
Without interruption	2,787	—	3,972	—	5,490	—	8,026	—
	miles							
Breakeven dev. distance								
With interruption	1.3		1.9		2.6		3.8	
Without interruption	1.2		1.7		2.4		3.5	

[a] Total investment costs include all development costs required of an adequately sized well. For the electric systems, the total investment costs include the cost of developing the electric line from the field edge to the center of the field at $1.50/foot.

[b] Fixed costs include depreciation, taxes, insurance and interest. Purchase costs are amortized over 7 years at an annual interest rate of 10.5 percent.

[c] Variable costs include fuel, lubricants, repairs, and labor. Fuel costs are based on $0.043/KWH for electricity and a diesel fuel cost of $1.10/gallon. The cost of electricity decreased to $0.027/KWH using an average interruptible service option.

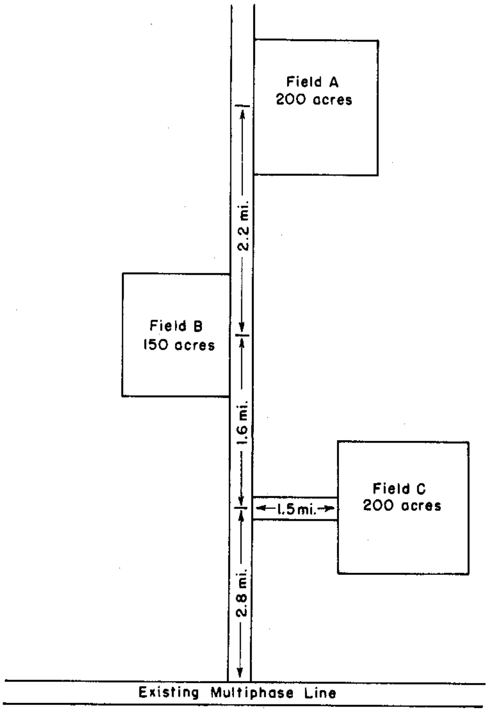

Figure 2. A Hypothetical Example of Market Failure in Multiphase Electrical Development.

costs of collective action. For example, should the owner of field A pay more of the development costs because his field is farthest from the existing line? While such problems may be resolved with private bargaining in the example in Figure 2, the transaction costs for joint private action would likely be prohibitive for a group of realistic size (Buchanan and Tullock; Kafoglis and Cebula) or where strategic bargaining is excessive. This research did not attempt to systematically measure the actual transaction costs associated with collective action among landowners. Instead, this research hypothesized that the lack of the development and use of multiphase electric power was evidence that transactions costs of collective action may have exceeded potential savings (revenues) from collective action.

One method which may reduce the need for private bargaining is subsidization of development by the EMC, which appears to be practical in some cases. To illustrate this possibility, assume that the producers in Figure 2 are served by an EMC that pays $6,000 per mile for power line construction and requires its customers to pay all of this construction expense. The savings between the $6,000 per mile cost and the average construction cost for the cooperatives in the State would be $10,235 which could be proportionally distributed among the customers of the EMC. Subsequently, the breakeven distances would increase to 7.1 miles for a 150-acre system and 10.2 miles for a 200-acre system. In this situation, private development is feasible for all fields. However, the incidence of costs will vary depending on who initiates the development. First, consider the owner of field A financing development to his field. The owner of field B could then install an electric irrigation system receiving a positive externality by paying no installation costs and the owner of field C would incur a construction cost of only $9,000. Since this charge is less than the amount of the entire construction, a positive externality also exists in this case. Alternatively, the owner of field C could finance construction to his field. Similarly, the owner of fields A and B could finance sequential construction to their fields. In this case, each owner would realize savings. Finally, the owner of field B could finance the construction and provide externalities to fields A and C. Only if one individual owned all fields would no externalities arise.

SUPPLEMENTING MULTIPHASE POWER DEVELOPMENT

This study presented evidence of the potential gains from developing multiphase power for agricultural irrigation. When these potential gains are inhibited by market failure, some form of supplement might hasten the development of multiphase power. A summary of the legislative provisions governing Georgia EMC's is helpful in this institutional analysis.

Prior to July 1, 1981, the EMC's were governed by the Georgia Electric Membership Corporations Act (Georgia Code, 1981). Section 34B-310 specifically prohibited electric suppliers from discriminating against or in favor of any consumer within a class of consumers or any class of consumers. Similar provisions in section 45-3-11 of the Georgia Code currently govern this requirement. Section 34B-115 prescribed certain requirements concerning rates, fees, rents, and other charges for electric energy, facilities, and supplies furnished by the EMCs. Among the more important requirements: (1) each EMC had to be operated without profit to its members, (2) receipts had to be sufficient to pay all operating and maintenance expenses, and (3) no EMC was able to accumulate funds or maintain any reserves. Section 46-3-340 of the Georgia Code contains the first two requirements and, thus, they still apply to EMCs. In addition, EMCs were and still are subject to the Public Service Commission except for matters that would fix rates, charges, and service rules and regulations.

Several of these provisions preclude certain institutional responses to collective failure. The prohibition against discriminatory rates would preclude even approximating the theoretical solution in Figure 1. For example, different development costs for farmers on the basis of size or type of irrigation system or for crops grown under the system are not legally possible. In addition, the provisions that preclude profits and accumulation of capital reserves would severely hamper financing the development by the EMC since equity capital would be unavailable. In 1981, this restriction was modified when the Georgia General Assembly repealed the existing legislation. The new legislation, The Georgia Membership Corporation Act included several new provisions (Georgia Code, 1982). Section 46-3-340 currently provides the authority for EMC's to accumulate reserves for future capital needs or to establish and maintain a reasonable capital structure. Therefore, power company provision of services would soon appear feasible.

INSTITUTIONAL ALTERNATIVES

Possible institutional alternatives to supplement frustrated markets for multiphase power include government provision, power company provision, and irrigation cooperatives. These alternatives address the problem of market failure by either: (1) shifting the transactions costs of collective activity from potential multiphase users to the government or the EMC's or (2) reducing the transactions costs of collective activity among potential multiphase users through new institutional arrangements. The distributional consequences of these institutional alternatives merit further discussion.

Government provision would result in development being subsidized by the general taxpayer. Contributions by taxpayers would be in proportion to taxes paid, regardless of potential benefits received from multiphase power development.[5] Users of multiphase power could earn benefits far in excess of their tax contributions. Governmental development of multiphase power to circumvent market failure for irrigation users may create conditions of non-market failure for other taxpayers who pay a disproportionate share of these costs. This potential wide divergence between the incidence of costs and benefits might make this alternative politically unpopular.

With power company provision, the divergence between the incidence of cost and benefits may not be as great. However, there may be resistance from residential power users if power companies attempt to shift development costs to residential users. Some of the political resistance from cross-subsidization of multiphase development could be mitigated by evidence of potential industrial growth and related employment in areas with multiphase power.

The final alternative would involve establishment of regional irrigation development districts to internalize development externalities and to manage the transactions costs of collective active (Hawkins, p. 93). Within each district, the development of multiphase power could be coordinated by an irrigation cooperative consisting of landowners and/or potential users of multiphase power. Using the incidence of cost and benefit criteria, irrigation districts may prove to be superior to government or company funded development. Since the activities of an irrigation district would affect each farmer in proportion to his investment, strong incentives would exist for efficient and responsive management (Hawkins, p. 93). However, some form of government guaranteed loans might be needed to assist the establishment of these irrigation crops.

CONCLUSIONS

Recent agricultural studies have focused on rising prices and unstable supplies of energy; however, the public good aspects of agricultural energy inputs have not been addressed. This analysis examined the development of multiphase electric power in a public good context using information obtained in a survey of Georgia EMC's.

[5] The problem of extracting a price (tax) from each consumer of a nonrival good according to benefits received is described by Randall as hyperexclusion (p. 135).

A theoretical explanation for market failure in multiphase power development and some preliminary empirical evidence of such market failure was presented. The impacts of market failure were measured by comparing the production costs savings of three-phase electric power to diesel fuel for irrigation. Despite the apparent cost advantages of multiphase power, its adoption for irrigation has been slow in areas where development costs must be borne by power consumers. Since individual investments in multiphase power construction are limited, its development in many areas has suffered from a failure of collective action.

Institutional arrangements were suggested as possible alternatives for this market failure. These were: (1) government subsidized construction, (2) multiphase development cooperatives that increase collective activity, and (3) subsidized construction by the power companies. Further research is needed relitive to the cost and consequences of these market supplements to multiphase power development.

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