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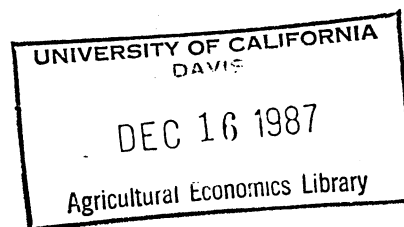
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A Simulation of Economic Effects of Technology Transfer in Cereal Production

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Grain

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A Simulation of Economic Effects of Technology Transfer in Cereal Production

This paper is concerned with the possible economic effects of technology transfer in cereal production from Alberta to Heilongjiang unit-farms in China. A simulation model is used to study the economic effects of exogenous changes in capital formation, production elasticities and the relative factor price ratio on labor demand, capital labor ratio and labor productivity in Heilongjiang. A labor demand function derived from production economics theory and a cohort approach are employed in the specification of both labor demand and supply relationships in the simulation analysis. Four scenarios are investigated in simulation. The results show that Alberta technology embodied in capital formation would promote cereal production in Heilongjiang. However unknowns in the ideal transfer situation of combined market reform, technology and capital formation such as institutional conflicts arising from the transfer process itself may inhibit success. More employment opportunity creation also appears to be required to accommodate a great amount of labor displacement by capital.

I. Introduction

Technical change as a thrust of growth and development in agriculture has drawn considerable new attention since the Green Revolution took place. China's open door to Western technology in agriculture reflects this technological emphasis. The principal Chinese objective is food security. Parallel attention is being given, however, to deconcentrated employment generation through economic diversification in rural areas. The open door constitutes technology transfer.

The implications of this transfer for agricultural employment are treated seriously in China. The transfer process is also raising questions relating to the cultural and organisational baggage accompanying the technology. These features of western economies and technology may be essential to successful transfer.

Heilongjiang province in China and the province of Alberta in Canada offer an opportunity to simulate the effects of technology transfer in agriculture. The agroclimatic features of both provinces bear enough resemblance to permit a simulation of the structural and employment impacts of transfer. Wheat occupies about fifty percent of the seeded acreage in both these northern provinces. Grain is grown on large commercial operations in the state farm system of Heilongjiang and on similar sized family operations in Alberta. The main differences are technological and structural on the production side and in processes of price determination on the market side. Labor intensiveness, low labor productivity and low capital labor ratio are the major features of Heilongjiang grain production.

A particular feature of the state farm system which dominates Heilongjiang agriculture is its record keeping. Each state farm is structured into sub farms for administration. Each sub farm is divided into unit farms for production management. The data for this research comes from unpublished unit farm records in 1984, the last year of their operation prior to the family farm reforms. Unit farms cultivated about 1,000 ha. each, involving from 20-50 families (Table 1). Their degree of mechanisation varied widely from farm to farm but was in general much higher than in the collective (commune) sector.

The research reported here addresses the three major issues of technology transfer; capital intensification, capital augmentation and factor pricing. Western grain production technology has evolved in an economy of increasing wages and decreasing relative real price of capital where the prices of labor and capital have been determined by a market process with some government steering. The structural result has been economies of size, stronger capital dominance in the factor mix, higher production elasticities for capital and lower elasticities for labor.

In Chinese state farm grain production, factor prices have been established institutionally. Farm size has been relatively fixed and capital has been augmented under circumstances of relatively low wages for labor and capital scarcity. The result has been underemployment on the farms, lower morale reflected in reduced labor motivation and lower elasticities of production for capital. This work did not document the pace of change in elasticities over time, but it is suspected that the "snapshot" elasticities measured with 1984 cross section data have not changed substantially in the last twenty years.

Alberta and Heilongjiang are twinned diplomatically enabling a growing exchange of scientific and technical information. The managers and directors within the state farm system are anxious to learn about western technology through their Alberta contacts, but also express concern over importing the capital labor structure inherent in Alberta technology. Alberta's agricultural industry is anxious to export technology to Heilongjiang and would like to address any impediments to that technological trade, such as the employment effects of their technology in China. This research simulates quantitatively the effects of transferring grains production technology to Heilongjiang. The criteria for assessing the impacts of alternative scenarios are the effects on cereal output, labor

demand in cereal production, labor productivity and capital labor substitution. The scenarios are 1) Hicks neutral capital formation, close to the approach used by the state farms so far, 2) changing technology manifested in the Alberta production elasticities, 3) changing the price determination mechanism to reinforce the induction/transfer of the Alberta-type technology and 4) technologically laundered capital formation coupled with price reforms, representing an often expressed preference in China for a development approach with minimum western technological influence, or alternatively the case of failed technology.

A simulation model based on conventional production economic theory and the concept of a *birth cohort* is used. An advantage of simulation is that synthesizing systems in model-form permits the exploration of systems that do not exist (Dent & Blackie, 1979). A Chinese cereal system based on western technology does not exist. The simulation enables insight on the labor release implications of transfer without taking the risk of actual experimentation.

II. The Technology Transfer Model

General Characteristics of The Model

The model consists of two submodels: labor demand and labor supply. The labor demand submodel is based on conventional production economics theory. A production function was selected to simulate the production process of grain on unit-farms in Heilongjiang. From the production function, a labor demand function is derived.

The labor supply submodel is built upon the concept of *birth cohort* in which a group of persons born in a given time period is followed through a span of life. It is supposed that the natural population growth rate and labor participation rate remain constant over a certain period of time. This cohort approach generates a stream of labor supplies. It is also applied to the process of capital formation and may be applied to other economic processes (Denton & Spencer, 1973).

Labor Demand Submodel

According to the classic theory of production economics, an input demand function can be derived from a given production function. Designating Y as output being a function of input factors, capital K and labor N_d , the following Cobb-Douglas form holds:

$$(1) Y_t = A K_t^{\beta_k} N_{dt}^{\beta_n}$$

where β_k , and β_n are production elasticity parameters estimated with the cross-section data from the Heilongjiang unit-farms and Alberta large farms respectively. The subscript, t , represents the dynamic sense of the function for use in the simulation. The symbol N_d indicates labor demand to distinguish it from labor supply expressed by N_s in the simulation.

The two variables of capital and labor are selected in the production function primarily because of the interest in the effects of Alberta mechanical technology transfer on the capital-labor relationship. Land areas were somewhat similar in the two cases and did not contribute to the qualities of the estimators. The Cobb-Douglas function was chosen because of its good performance relative to other specifications tested with the Heilongjiang data (Table 2).

In general, deriving demand functions for inputs follows the rule:

$$MVP_{x^1} = P_{x^1}; MVP_{x^2} = P_{x^2}; \dots MVP_{x^n} = P_{x^n}$$

where $x^1, x^2 \dots x^n$ are factors of production. The equations are solved simultaneously for inputs $x^1, x^2 \dots x^n$, where MVP_{x^n} is the marginal value of product of input x^n . In this case, only the labor demand function is to be derived. However, due to the importance of investigating the substitution between capital and labor in this study, an equation of marginal rate of substitution between capital and labor is selected as a starting point. Thus the following relation holds (Doll & Orazem):

$$(2) \text{MPP}_k / \text{MPP}_n = P_k / P_n = \rho$$

where MPP_k is the marginal physical product of capital and MPP_n is the marginal physical product of labor². P_k is the capital price and P_n , the labor price. ρ represents the price ratio of capital and labor. Equation (3) can be obtained from Equations (1) and (2).

$$(3) \rho = (\beta_k / \beta_n) (N_d / K_t)$$

Deriving N_d from equation (3) produces equation (4):

$$(4) N_d = \rho K_t (\beta_n / \beta_k)$$

To investigate the impact of changes in capital formation alone on labor demand, suppose capital formation of unit-farms in Heilongjiang (K_h) can catch up with that of Alberta (K_a) in an arbitrary period of 20 years. The annual growth rate of K_h (k) following a compound path may be obtained as follows:

² As our production function is expressed in value terms, there is no difference between MPP and MVP.

$$(5) k = (K_a/K_h)^{0.053} - 1$$

where $0.053 = 1/(20 - 1)$

Capital formation for unit-farms along the time path can be represented in a cohort equation such as:

$$(6) K_t = K_0 (1 + k)^t$$

where K_0 is the capital value of unit-farms in the initial year of the simulation.

To investigate the impact of changes in factor elasticities, the elasticities of capital and labor can be supposed to reach the levels of those in Alberta in 20 years. Using the same method to get the annual rates of change of those production elasticities:³

$$(7) \epsilon_k = (\beta_{kh}/\beta_{ka})^{0.053} - 1$$

where ϵ_k represents the annual rate of change of elasticity of capital in unit-farms. β_{ka} is Alberta's elasticity of capital and β_{kh} the elasticity of capital for unit-farms in Heilongjiang.

$$(8) \epsilon_n = (\beta_{na}/\beta_{nh})^{0.053} - 1$$

where ϵ_n refers to the annual change rate of elasticity of labor in unit-farms. ϵ_{na} is Alberta's elasticity of labor and β_{na} the elasticity of labor for unit-farms in Heilongjiang.

β_{ka} and β_{na} are estimated from Alberta's grain production function, using capital and labor in a Cobb-Douglas form.

By adjusting ϵ_k and ϵ_n , the elasticities of capital and labor on Heilongjiang unit-farms may be made to approach those of Alberta in 20 years. This approach represents a gradual process of substitution of capital for labor on unit-farms. The following two equations represent the process:

$$(9) \beta_{kt} = \beta_{k0} (1 + \epsilon_k)^t$$

$$(10) \beta_{nt} = \beta_{n0} (1 + \epsilon_n)^t$$

where β_{k0} and β_{n0} are the values of β_k and β_n for Heilongjiang unit-farms in the initial year.

Different price ratios apply for unit-farms in Heilongjiang (ρ_h) and Alberta's farms (ρ_a). According to the principle of induced innovation, technology change is a function of relative factor prices, which implies that a new technology is induced to facilitate the substitution of increasingly more expensive factors for less expensive factors (Hayami & Ruttan, 1985). The idea implied here is

³ At a point in time, β 's are fixed or constant elasticities. Over time, however, they may be altered by technology.

that to achieve the technological change or the successful technology transfer from Alberta to Heilongjiang, compatible relative factor prices are required.

To investigate the impact of changes in ρ on labor demand, suppose ρ_h approaches ρ_a in 20 years. The annual change rate is:

$$(11) \delta = (\rho_a / \rho_h)^{0.053} - 1$$

Therefore, what is simulated is the gradual evolution of a price discovery process in China to reflect changes in relative factor costs and productivities. This process is demonstrated by:

$$(12) \rho_t = \rho_0 (1 + \delta)^t$$

where ρ_0 is the ratio of the price of capital to the price of labor in the initial year of the simulation.

By definition, the capital/labor ratio is of the form:

$$(13) \eta = K_t / Nd_t$$

where η represents the capital/labor ratio.

By definition, labor productivity is expressed as follows:

$$(14) \theta = Y_t / Nd_t$$

Substituting equation (1) in (14), the expression for labor productivity becomes:

$$(15) \theta = (A K_t^{\beta_k} Nd_t^{\beta_n}) / Nd_t$$

Labor Supply Submodel

The concept of *birth cohort* is used to estimate population change over time. The population function is of the form:

$$(16) P_t = P_0 (1 + p)^t$$

where P_t represents population within a time path, P_0 is the population in the initial year, and p is the natural population growth rate specified exogenously.

Assume the labor supply function is:

$$(17) Ns_t = R_t P_t$$

where Ns_t represents labor supply along a time path, and R_t represents a labor participation rate, shaped as follows:

$$(18) R_t = R_0 (1 + r)^t$$

where R_0 refers to the initial value of labor participation rate and r is the annual change rate of R_0 . The value of r is determined exogenously.

By definition, it may be postulated that:

$$(19) Ns_t = Nd_t$$

This equilibrium normally would occur only in a perfectly competitive economy. In cases of chronic or potential surplus labor, the gap (G) between labor supply and demand may be expressed as:

$$(20) G_t = Ns_t - Nd_t$$

where G is surplus labor in each time period corresponding to changes in labor supply and demand over time.

III. Model Application

Four Scenarios

The above model is used to simulate the impacts of grain production technology transfer from Alberta to a representative Heilongjiang grain unit farm according to four different scenarios.

Scenario One: Capital formation on mechanised unit-farms in Heilongjiang catches up with the 1981 capital levels of Alberta's large grain farms in 20 years, with other factors unchanged. The impacts on labor demand, capital/labor ratios and labor productivity are derived.

Scenario Two: Capital formation and the production elasticities of capital and labor reach the 1981 levels for Alberta simultaneously in 20 years, with other factors unchanged. This simulation attempts to synthesize the impacts of technology transfer by means of capital formation where new labor saving technology is embodied in capital.

Scenario Three: Capital formation, production elasticities of capital and labor and the price ratio of capital to labor simultaneously approach the 1981 levels for Alberta in 20 years. This scenario explores the impacts of technology transfer where the technology reflects capital-augmentation and deepening together with relative factor price changes.

Scenario Four: Capital formation and the price ratio of capital to labor move to the 1981 levels of Alberta in 20 years, with production elasticities unchanged. This scenario tries to find the impacts of capital formation linked to relative factor costs and productivities, when wage rates are

increased without technological change which would enable capital substitution for labor.

Data Analysis

A random sample of 5 state farms was selected from 84 state farms (BLRA, 1985). Twenty two cereal unit-farms were selected randomly from 91 cereal unit-farms within the 5 selected state farms. The 1984 agricultural census and statistical yearbooks as well as farm profiles provided the sampling frames. All data were cross-sectional. For the purpose of international comparison, Chinese yuan were converted to Canadian dollars at an average exchange rate of CAN 1\$ = 1.9 yuan for the year of 1984. The data for Alberta farms were obtained from the 1981 Census of Agriculture (Statistics Canada). The forty-two large farms in the census, whose sizes approximated those of the Heilongjiang unit-farms, from all 15 census divisions in Alberta, were used. Input variables of the Alberta farms included machinery value and labor.

The data for the Heilongjiang unit-farms and Alberta farms were analyzed using the OLS part of the SPSS-X statistical package on the Cobb-Douglas production function. The estimates and results of the first order tests are presented in Table 2.

The estimated production functions form the technical base of the simulation model. All the estimates and other exogenously specified variables constitute the set of given data. To simulate the previously mentioned four scenarios in the model, a FORTRAN language program, briefly presented in a simple flow chart (see Figure 1), is used.

IV. Results

The model simulates the changes on an average mechanised unit grain farm following a twenty year program of technology transfer from western Canada. Table 3 provides the initial structural and performance characteristics for this representative farm. The departures from these conditions corresponding to each of the four scenarios are in the last four columns of the table.

The first scenario simulates Hicks neutral capital formation.⁴ As capital increases, labor demand increases proportionally. Therefore the capital/labor ratio remains constant over time. The consequent change rate of labor demand exceeds that of labor supply resulting in a shortage of labor

⁴ Herrick & Kindleberger, "Hicks neutrality: description of one variety of technological change in which the optimal factor proportions remain constant despite the change." See *Economic Development*, 1983, p. 514.

by the 20th year of simulation. Although this strategy absorbs considerable labor, it makes a modest contribution to the growth of production and labor productivity (Table 3, column 2).

The results of Scenario Two as expected show that when capital formation is accompanied by labor-saving technology, labor demand declines. Although increases in capital formation result in some increase in labor demand, the labor-saving nature of Alberta's technology (β_k increases, β_n decreases) constantly displaces labor, so that the general tendency of labor demand in this situation is to decline. Consequently the capital/labor ratio constantly increases (Table 3, column 3).

Transfer of Alberta's capital-using technology increases the contribution to growth in output of capital embodied technology relative to that of labor. Thus output increases 34 percent compared to 96 percent in Scenario One. The decrease in labor demand and increase in output are the principal contributors to the marked improvement of labor productivity over Scenario One.

The results of Scenario Three indicate that capital formation with labor-saving technology and labor price adjustment would decrease labor demand by 99% which translates into the highest labor productivity of all scenarios. The price ratio of capital to labor in Heilongjiang is 0.00067, while that for Alberta is 0.00001.⁵ The decrease in labor demand under the allocative efficiency rule precedes the absorption of the new technology reducing the total output in every simulated year.

Adjustment of the price ratio of capital to labor to that in Alberta in Scenario Four was the same as for Scenario Three again causing labor demand to decline under market circumstances. The rapid decrease in labor demand reduced total output by 93 percent relative to the base year. However, labor productivity still increased due to the faster speed of displacement of labor compared to the decline in total output. The capital/labor ratio increases dramatically 72 fold as capital formation continues and the labor inputs keep decrease under market pressure without labor saving technology (Table 3, column 5).

V. Interpretation

Scenario One entails a large amount of capital investment, with a corresponding increase in labor input. Consequently the capital/labor ratio remains constant during the simulation period. This scenario is considered to be similar to the early stage of state farm development in Heilongjiang.

⁵ These figures are calculated from equation (3) by the authors.

Capital formation principally oriented to land reclamation kept increasing, but was accompanied by labor shortages. These shortages were overcome by migration from elsewhere in China. Thousands of young students from all over China moved into Heilongjiang in the 1960's and 1970's. The result of this development strategy was near stagnation of labor productivity, which impeded agricultural development in Heilongjiang during that period of time⁶.

The strategy inherent in Scenario One requires a continuing injection of exogenous financial investment, due to the limited investible surplus from grain farm operations. Accordingly with consideration of financial constraints and a need to improve technical and economic efficiency, this scenario can no longer satisfy the development objectives on the state farms.

Scenario Two introduces the impacts of a labor-saving technology embodied in capital formation. Not only would the labor requirement not increase but workers would be displaced over time. This scenario is evidence of a labor surplus or underemployment in the cereal operations of the state farms even before labor saving changes are introduced because labor can be withdrawn from cereal production while output grows (Reynolds 1975).

Scenario Three examines the transfer of a comprehensive package of western technology by means of capital-intensive methods coupled to adjustment of relative factor prices. This scenario extends Scenario Two by acknowledging the importance attached by development economists to prices for inducing technology and to efficient factor markets (Hayami and Ruttan, 1985). Alberta's price ratio of capital to labor, with production elasticities of capital and labor and capital formation taken together, represent a complete transfer of cereal production technology and its factor market environment.

The price ratio of capital to labor of Alberta, following the induced technology hypothesis, should enhance the transfer. Certainly the ratio reflects efficiency of resource use and development of capital formation in Alberta where the technology originates. However cereal output declines during all years in Scenario Three where market price adjustments precede technological enablement of factor recombination. Adjustments promoted by changes to the price ratio appear to lead to a shift of labor out of the cereal enterprise thus impairing the level of output. This simulated scenario provides some

⁶ Heilongjiang GYNCJJFZS BianXieZu, *op.cit*, p. 217.

evidence about problems with technology transfer into an economy with different relative prices of capital and labor. A too hasty reform of the wage structure running ahead of technological improvements could jeopardise food security.

Market prices in most countries usually do not reflect either the true scarcity values or the marginal productivities of resources used ⁷. Present wages in Heilongjiang do not reflect labor marginal productivity. The wages are lower than the marginal value product of labor on cereal unit farms by about a factor of six. This differential may be partially accounted for by perquisites. However, the wage bill does not seem to be keeping pace with productivity gains even considering the equal wage policy for redundant labor. In reality the price adjustments of Scenario Three are very unlikely in that they are large and constitute a reversal of current wage policy in China. Furthermore capital financing, though similarly priced to that in Alberta, is strictly rationed. The scenario does suggest, however, that technological transfer as a means of augmenting price induced technological change should stay ahead of reforms of factor markets. Put another way, factor pricing policy seems to be as critical as technological change in the agricultural growth process.

Scenario Four explores the impacts of a technology transfer by means of capital formation and adjustments to factor combinations 'forced' by an efficient response to changing relative factor prices. In this scenario capital formation is without any consideration of technology change. It could be some sort of labor-using technology, like new capital construction, or any kind of job creation, which can absorb the labor not required in cereal production under the efficiency rule. Or, it could be a case of a failure of new cereal technology to enable labor displacement. This scenario implies that capital formation alone could not offset a syphoning off of labor from cereal agriculture caused by higher labor opportunity costs. Results in Scenario Four show that this scenario fails on all counts. The changed price ratio, with production elasticities unchanged and capital formation only, is an example of the possible effects of a closed door policy on technology while domestic economic reforms of the wage structure are pursued with continued injection of government funds into the state farms. Put another way this scenario illustrates the possible effect of pushing wage reforms ahead of the pace of technological change.

⁷ Herrick & Kindleberger, *op.cit.* p. 289.

VI. Conclusions

A transfer of western cereal production technology to Heilongjiang would be best achieved with capital formation in the absence of changes to relative capital and labor prices in Scenario Two (Table 4). Output would increase 324 percent over the base year. However the labor gap would double. If the price of labor relative to that of capital is increased to levels approaching those in Alberta along with capital formation embodying labor saving technology, output would decline. However labor productivity would increase to 96 times that in the base year due almost entirely to labor displacement to other forms of employment. To invest heavily in cereal production, increase wages and not use labor intensive technology or have the labor-saving technology fail as in Scenario Four would be the worst possible situation (Tables 3 and 4).

The failure of Scenario Three which depicts the ultimate complete transfer situation as often imagined by Chinese and Canadians is evidence that similar agroclimatic circumstances are not sufficient to ensure success. Unknowns require research and institutional differences arising from the process of technology transfer itself are two other considerations to be addressed.

The simulations demonstrate once again that agricultural development requires an opportunity cost for farm labour. Displaced labor requires opportunities for employment, otherwise economic reforms in the pricing of labor and capital coupled with technology transfer in cereal agriculture will place an intolerable burden on the wage equity policy. Rural development through diversification away from cereals would seem to be required to accompany labor-saving technical transfers to cereal production in Heilongjiang.

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Figure 1. A Flow Chart of The Simulation Structure.

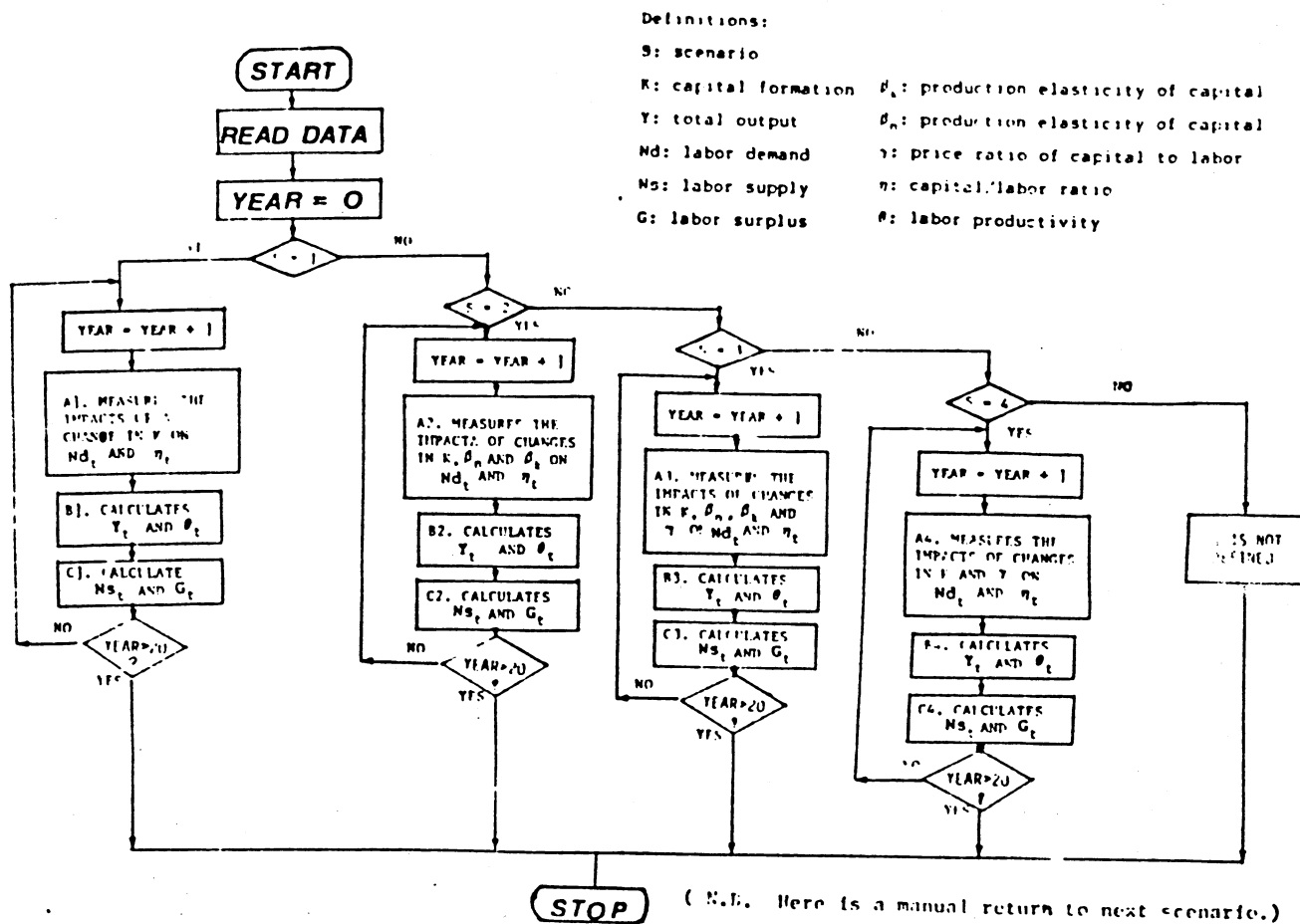


Table 1. General Information of the Two Samples of Grain Farms Heilongjiang and Alberta, 1984 CDN \$.

Variable	Heilongjiang (1984) n = 22			Alberta (1981) n = 42		
	mean	minimum	maximum	mean	minimum	maximum
output per farm (\$)	539,889	127,508	1,049,782	257,673	67,463	771,830
labor (people)	186	90	329	2	1	9
capital(\$)	162,391	70,100	317,900	281,954	141,984	599,129
culti. area(ha.)	978	370	1,935	673	297	1,826
output/labor ratio	2,862	1,417	3,763	138,249	37,510	290,936
capital/labor ratio	886	609	1465	164,896	46,010	299,564
land/labor ratio	6	4	11	405	82	1,031
capital/land ratio	166	189	164	419	478	328

Source: Unpublished unit-farm records in Heilongjiang and unpublished retabulated 1981 census data for grain farms in Alberta (Statistics Canada).

Table 2. Estimates of Production Functions For Heilongjiang Unit-farms 1984 and Alberta Large Farms 1981.

Subject	Alberta (n = 42)	Heilongjiang (n = 22)
A	4.1 (1.33)	4.4 (3.10)**
β_k	0.64 (2.58)*	0.39 (2.10)*
β_n	0.43 (2.75)**	0.79 (3.92)**
F-test	27.29**	62.42**
R ²	0.58	0.87

Source: Results of production function analysis.

Note:

A: the constant of the Cobb-Douglas production function in natural log value.

β_k : the production elasticity of capital.

β_n : the production elasticity of labor.

Figures in parentheses are t-values, with significance level indicated by * (5%) and ** (1%).

Table 3. Results of the Simulation of the Transfer of Grain Production Technology Over 20 Years from Alberta to a Representative Unit Grain Farm in Heilongjiang Using Four Scenarios, 1984-2004.

Item	Base Year Situation	Change Over 20 Years From the Base Year for Scenarios			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Labor supply (people)	257	+25%	+25%	+25%	+25%
Labor demand (people)	188	+77%	-46%	-99%	-97%
Labor gap (people)	69	-119%	+216%	+360%	+356%
Capital stock (\$CDN 1000)	162	+77%	+77%	+77%	+77%
Capital/labor ratio (CDN/person yr)	867	constant	+227%	+23694%	+7187%
Production (\$CDN 1000)	548	+96%	+324%	-28%	-93%
Labor productivity (\$ CDN/person yr)	2924	+11%	+681%	+9610%	+173%

Notes:

Scenario 1: Hicks neutral technological change in capital formation only.

Scenario 2: Capital formation with labor saving technology.

Scenario 3: The entire western package, capital, labor saving technology and western relative factor prices.

Scenario 4: Hicks neutral technological change in capital formation with western relative factor prices.

Table 4. Ranking of Scenarios For Technology Transfer in 20 Years For Heilongjiang According to Four Criteria.*

Subject	Y	Nd	Y/N	K/N	Σ
Scenario #1	2	1	4	4	11
Scenario #2	1	2	2	3	8
Scenario #3	3	4	1	1	9
Scenario #4	4	3	3	2	12

Source: Simulation results.

* On this four point scale, the smaller the number is, the better the scenario is judged to be.

Y: output.

Nd: labor demand.

Y/N: labor productivity.

K/N: capital/labor ratio.

Σ : the total ranking.