

Simulation of the Optimal Structure of a Regional Transport System

Terry Heaps, John M. Munro and Christopher S. Wright
Department of Economics
Simon Fraser University
Burnaby, BC V5A 1S6

This paper uses simulation techniques to explore the optimal configuration of a railway branchline system serving an agricultural region. The simulation is based on a model which incorporates cost and demand relationships in the markets for grain production and transportation.

The design of the model is based on certain characteristics of the Prairie region of Western Canada, although the region modelled in this paper is about ten percent of the size of the actual Prairie grain growing region. In this region the grain industry is very important economically and has received extensive policy attention from Canadian governments over the past century (see, Economic Council of Canada (1988) for an overview). The transportation of grain has been regulated and subsidized according to various policy regimes. Consequently, the design of policies which would improve the industry's performance has revived considerable research attention.

Simulation techniques are an attractive method for examining the effects of different policies under varying industry and market conditions. These techniques have been widely used in other studies involving the Prairie grain industry. For example, simulation has been used to study the optimal configuration of the country elevator system (Ash and Yagar 1977), the effects of changes in Crow freight rates and branchline system length on grain production costs for different sized farms (Fleming and Uhm 1982), the effects of progressive abandonment of a regional branchline system on the costs of collecting and handling grain (Tyrchniewicz and Tosterud 1973), and the effect of con-

An earlier version of this paper was presented at the 37th North American Meetings of the Regional Science Association, Boston, MA, 1990. Two anonymous referees of the journal provided useful comments.

solidation of the grain collection and transportation system on the total costs of growing grain and transporting it to port (Kirkland 1975). On a larger scale, simulation has been used to model the effects of changes in the Crow Rate on the Prairie macro-economy and its component industries (Norrie and Percy 1983) and the settlement process on the Prairies (Lewis 1981; Borins 1982). However, we are not aware of other research which has used a location-theoretic model as the basis for its analysis. This paper examines the results of simulation experiments concerning several possible transportation and production policies with respect to their effects on the structure of the grain transport system and the performance of the industry. The following policies are examined:

1. railway subsidy;
2. railway tax;
3. grain production subsidy;
4. grain production tax;
5. grain land subsidy;
6. grain land tax;
7. railway price regulation.

In addition, we also examine the effects of world grain price levels and relative costs of different modes of transport.

The Model

Basic Assumptions

Since most Canadian grain is exported and since Canada does not set prices for export grain, the at-port price for grain can be treated as exogenous.¹ The difference between the at-port price and the cost of growing grain determines the maximum that farmers are willing to pay for collection, handling and transportation of grain. If these latter costs do not exhaust the amount remaining after grain growing costs are taken into account (plus subsidies and less taxes), then there will be a surplus, or rent. We would expect that the various participants in these activities -- grain producers, elevator companies, trucking companies, the railways, and government -- would each endeavour to maximize their own perceived surplus.

1. Mitchell and Duncan (1987) present econometric evidence in support of the view that the grain price is exogenous in the Canadian grain market.

The Region

The model's region is a featureless plain with varying shape containing 40,000 square kilometres with sides approximately 200 kilometres in length. Sixty percent of the region is cultivable; this land is assumed to be equally productive in growing grain. The region is surrounded by adjacent complementary regions;² thus the cultivated area cannot increase beyond the initial 24,000 square kilometres of cultivable land. Once all land is being cultivated, increased grain output can only occur through higher grain yields.

A network of roads connects each farm to the nearest grain elevator via a straight-line route. Each elevator services a catchment area which delivers all its grain to that elevator for transfer to the railway. At any given time, all catchment areas are the same shape and size and the country elevators are spaced equidistant throughout the region. Some of the country elevators are located on the railway mainline but most are placed along the railway branchlines.

A mainline railway crosses the centre of the region in an east-west direction. A north-south branchline railway network, consisting of a linked series of Y-shaped lines, connects the country elevators to the mainline. The first elevator is located on the mainline and others are located according to a planned design which will result in an efficient branchline configuration when the region is fully cultivated and served by a predetermined number of elevators. (An efficient configuration is one in which the length of the branchline network is minimized).³ As an example, Figure 1 shows the region with 64 elevators and a branchline network of 1302 kilometres.

Demand and Cost

The model has the following basic characteristics (for more details on the model, see Heaps et al. (1992)). Grain farmers are profit-maximizers and grow grain on farms of equal size according to the same production function but with varying intensities of cultivation. The grain is brought to elevators by farmers' trucks. Each elevator buys grain from all the farms located in its

-
2. While the region's area is constant, its shape changes as the number of elevators changes and it is always identical in shape to the contiguous regions.
 3. The average length of haul for grain on branchlines is not minimized by this form of branchline structure; a V-shaped branchline structure would do that. The Y-shaped branchline structure minimizes the total length of the branchline network. We chose it because the fixed costs of building and maintaining the branchline network are more important than the costs of running trains over it. According to the Report of the Commission on the Costs of Transporting Grain (1977), line-related costs represent 95 percent of the costs of grain-dependent branchlines and volume-related costs only 5 percent.

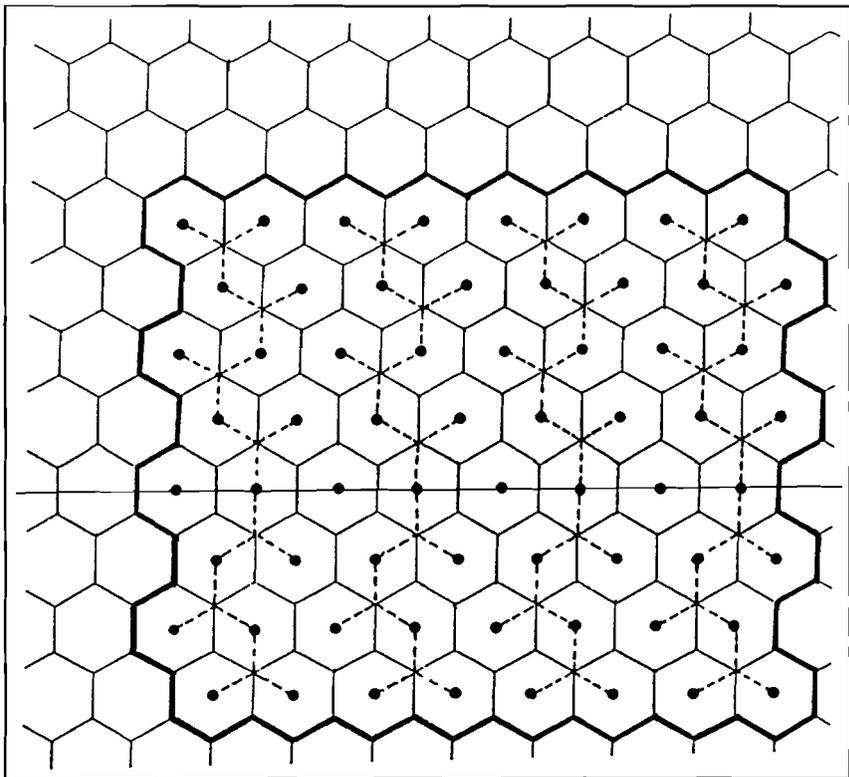


FIGURE 1 The Region with Sixty Four Elevators

- - - - railway branchlines;
- railway mainline (the horizontal line);
- catchment area boundaries;
- region boundary;
- grain elevator location.

catchment area. From there it is sold to the railway for shipment to an export port. Farmers' grain production decisions are based on grain production costs, the cost of transporting grain from farms to elevators, and the price received for grain at the elevator. The price which the elevators are willing to pay for grain is determined by the cost of handling grain at elevators, the cost of transporting grain from elevators to seaports by railway branchline and mainline, and the world export price for grain. The railway, like the farmers, is a profit-maximizer and its decisions depend on its market type: competitive, monopolistic, or regulated.

The basic elements of the model are as follows:

Demand for Grain	the world price of grain (P_W) is exogenous;
Cost of Growing Grain	$C_G = f(t)$ where t = yield per square kilometre;
Cost of Trucking	$C_T = f(r)$ where r = distance from the nearest elevator;
Cost of Grain Elevation	$C_E = f(Q)$ where Q = average throughput per grain elevator;
Cost of Railway Transportation	$C_R = f(NQ, L_{NW}, L_W)$ where N = number of elevators, L_{NW} = total length of the branchline network, and L_W = average branchline haul of grain.

The interaction of the cost relationships with the demand relationships determines the behaviour of farmers, elevator operators, and the railway. With a given export price, changes in the branchline configuration affect the returns received by farmers, elevator companies, and the railway. Longer branchlines are associated with increases in cultivated land, in grain production, and in the number of grain elevators. Actual decisions are governed by the particular policy regime which is in force. The optimization process for these interrelated decisions is quite complex. Exactly what happens depends on the interactions revealed as the system of equations is solved simultaneously.

Phases of Grain Production

The locational pattern of farming is determined by the interaction between the configuration of the railway branchline system and farmers' production decisions. The locational pattern of grain production falls into one of three phases. The model parameters determine in which of the three phases an equilibrium will occur.

Settlement Phase	--	when there is vacant land and the grain elevator catchment areas are circular and do not overlap;
Transition Phase	--	when there is vacant land but the elevator catchment areas touch and are part circle and part hexagon;
Mature Phase	--	when there is no vacant land and the elevator catchment areas are hexagons.

Because of the effects of trucking costs, grain output per square kilometre within the elevator catchment area is highest at the elevator and declines as distance from the elevator increases. At the periphery of the elevator catchment

area the yield is at the level where average cost equals marginal cost. This phenomenon is familiar in location theory as determining the margin of cultivation in von Thunen's classic land use model. In that model, transport of grain by horse involved physical consumption of the product and resulting lower net yields as distance from the market increased.

During the Settlement and Transition Phases the yield at the periphery is fixed in relation to the yield at the centre. Therefore, increases in the trucking cost differential between the centre and periphery increase average yields across the region. During the Mature Phase, the most efficient way to increase grain output is to increase yields across the region through more intensive (and costly) cultivation methods.

Surpluses

The economic rent (surplus) associated with the production, collection, and transportation of grain can be separated into six types.

1. Consumer Surplus. This is the difference between the actual price of grain and the price consumers of Canadian grain would be willing to pay for it times the quantity of Canadian grain consumed in the world. We ignore consumer surplus. Since most grain is exported, surpluses occurring in other countries are not likely to be a relevant consideration in forming or evaluating Canadian public policy.
2. Producer Surplus. This occurs if some producers of grain have access to better or cheaper inputs and so are able to grow their crops at a lower per unit cost. Producer surplus is not recognized in the model. We assume that all farmers are equally skilled, that all land is equally fertile, and that the same grain-growing technology is available to all grain producers.
3. Elevator Surplus. We assume that there are no monopoly rents generated in the elevator system. While the grain elevator industry is concentrated enough for oligopoly behaviour to occur, most elevator capacity is owned by producer cooperatives. Also, any elevator market power would probably be over-shadowed by railway market power.
4. Production Surplus. This occurs whenever the marginal cost of growing grain is greater than the average cost. There are two types of production surplus: a. Location Production Surplus occurs because trucking costs are higher as distance from the elevator

increases. Higher trucking costs mean lower yields at locations towards the periphery, and; b. Regional Production Surplus is the residual production surplus after account has been taken of the location production surplus. Unlike location production surplus, regional production surplus is the same on all land in the region, including land which lies on the periphery of cultivation.

5. Transportation Surplus. This surplus is the difference between what grain producers pay for railway transportation and the cost of supplying the service. If there were perfect competition in the supply of railway transportation or if the market for this service were perfectly contestable, this rent would be zero (we assume that there are no monopoly rents associated with truck transportation because the service is provided either by farmers themselves or by commercial trucking firms in a competitive market environment).

Markets

The model predicts the effects of surplus-maximizing behaviour on the size of the grain producing area, the level of grain production, and the configuration of the transportation and collection system. The effects of four different market types are considered.

1. Farmer Monopoly. In this market the railway behaves as though there are competing firms supplying grain transport service. Railway freight rates are set to equal railway average cost and there is no effort by the railway to exploit market power. This could be because the government regulates the railway or, as the theory of contestable markets would argue, because the railway does not have market power due to the underlying cost characteristics of the industry and the threat of entry. With a single grain producer in the region (farmer monopoly), the branchline/elevator system would be established according to the maximization of production surplus by the farmer.
2. Perfect Competition. Again, the railway behaves as though there are competing firms supplying grain transport service and sets rates to equal railway average cost. If there were many grain producers (perfect competition), the expansion of the system would continue, perhaps until all surpluses were exhausted by the burden of high railway branchline and elevator costs. The interest in more elevators and branchlines is driven by producers' desires

to increase their locational surplus, which is associated with location near an elevator.

3. Railway Monopoly.⁴ Here the railway uses its position as the dominant mode in transporting grain from the growing region to the ports to control the collection segment of grain transport. The railway prices grain transport service so as to maximize its profits by obtaining as much of the social surplus as possible.⁵ If it were completely successful, the railway would crowd out most of the potential regional and location production surpluses.
4. Social Monopoly. In the fourth market type, government policy is designed to maximize the sum of the three surpluses. This requires control over both railway pricing and the configuration of the branchline system (it also requires appropriate policies with respect to highway transportation and the provision of elevator services -- these are embodied in the assumptions of the model).

In each market, the nature of cost relationships determines the behaviour of the various participants in the activities of grain production, collection, and distribution. The structure of these activities and the interaction between them is central to the working of the model.

Simulation Results

In using the model for simulation, several of the parameters are defined as constants, with the values based on representative Prairie conditions for 1985. These values are shown in the Appendix. The simulation results are reported in summary form in the following sections using tables which show the characteristics of the optimal grain transport system for each market type as certain parameter values change.

The following is a glossary of the symbols used:

- N = number of country elevators;
 L_{NW} = length of branchline network in kilometres;

-
4. In the model, the railway is portrayed as a monopsonist. It exercises its market power through the purchase of grain from the farmers for transportation to the port. However, in the real world, the railway is a monopolist. It does not actually purchase the products it transports -- it sells transport service to those who own the goods being transported.
 5. Research on the success of coal-hauling railroads in the United States in capturing the rents associated with the transportation of coal for the generation of electricity estimates rent capture between 6 and 38 percent (Zimmerman 1979; Garrod and Miklius 1987).

- P_E = grain price f.o.b. elevator in dollars;
 m = interior angle of the grain catchment area (0 degrees for circular shape, 30 degrees for hexagonal catchment area shape);
 r_{max} = maximum trucking distance from farm to elevator in kilometres;
 NQ = total grain output in the region in tonnes;
 AC_G = average cost per tonne of growing grain in dollars;
 P_R = railway grain demand price in dollars;
 S_S = total surplus (the value of regional grain output in terms of its world price less the costs of resources required for its production, elevation, and transportation, in millions of dollars);
 S_{RG} = regional production surplus (surplus resulting from the increasing intensity of cultivation in the Mature Phase, in millions of dollars);
 S_{LN} = location production surplus (surplus resulting from differences in location within the region with respect to elevators, in millions of dollars);
 S_T = transportation surplus (surplus available for railways, in millions of dollars).

The first simulation run is the base case -- the world price of grain and trucking costs are at their 1985 levels and there are no subsidies or taxes used as special policy instruments. Subsequent simulations examine the effects of changing certain key parameters.

1. The value for P_W is set at \$160.75 per tonne in the base case. What difference does it make if grain prices are lower?;
2. The existing branchline system was constructed when the costs of hauling grain to country elevators by wagon was much higher than today's trucking costs. Is the current branchline system an artifact of relative modal transport costs of 90 years ago and what difference does it make if we change the relative size of railway and trucking costs to reflect more closely the situation of the early 1900s?;
3. Subsidies have been an important feature of Prairie grain production and transportation for many years. What happens, according to the model, if we add subsidies (or taxes) to the system? Do they move us towards the social optimum and what difference do they make to the configuration of the transport system and the levels of grain production and surpluses? What are the effects of different types of

subsidies and taxes?;

4. The rates charged for railway grain transportation have been regulated. What effects might this regulation have had on the transport system and the production of grain?

Base Case

Table 1 shows the simulation results for the base case. Looking first at the farmer monopoly results, the optimal branchline/elevator system consists of 11 elevators and 431 kilometres of branchlines and the maximum truck haul to an elevator is 37.4 kilometres. All the region is cultivated and grain catchment areas are hexagonal ($m = 30$ degrees). A total of 3,444,000 tonnes of grain is produced at an average cost of \$92.35. The railway pays \$115.53 per tonne for grain at the elevator and the total social surplus, all of which is regional production surplus and location production surplus received by the grain producer, is \$79,810,000.

If we introduce a large number of independent grain producers (perfect competition), we find a different outcome. A vast branchline/elevator network is built -- more than 1143 elevators and 6106 kilometres of branchline so the longest truck haul is less than 4 kilometres. What happens is that individual grain producers, seeking to maximize their own particular S_{LN} , persuade the railway, which is a passive participant in this market type and only requires that its costs be covered, to continue building branchlines until all surpluses net to zero (the similarity to the zero rent equilibrium outcome in exploitation of a common property resource is obvious).⁶ The whole region is cultivated, but the intensity of cultivation drops as yields are forced down by the necessity to grow grain more cheaply to support the branchline/elevator system (the railway pays less than \$87.71 for grain delivered to the elevator and AC_G is \$87.60) and only about 2.6 million tonnes of grain are produced.

If the railway operates as a monopoly, maximizing its own surplus, the configuration of the transport system is the same as under farmer monopoly. However, there is a small amount of uncultivated land in the region and total production of grain is only 2,639,000 tonnes. The railway pays \$90.21 for grain delivered to the elevator (and would be willing to pay \$114.32 (P_R) but does not because its decisions are made so as to maximize its profits). Total social surplus is \$68,720,000 - over \$66 million of this is transportation surplus (railway profit) but a small amount of locational surplus exists as well.

6. The inequalities in Table 1 indicate that this point was not actually reached in the simulations. However, it does not lie very far beyond the values shown in the table. Similar results occur for Perfect Competition in the other simulations.

TABLE 1 Optimal Grain Transport System Simulation Results-Base Case

	Farmer Monopoly	Perfect Competition	Rail Monopoly	Social Monopoly
N (no.)	11	> 1143	11	11
L_{NW} (km)	431	> 6106	431	431
P_E (\$)	115.53	< 87.71	90.21	116.64
m (deg.)	30	30	29.31	30
r_{max} (km)	37.4	< 3.7	37.2	37.4
NQ ('000 t)	3444	< 2608	2639	3479
AC_G (\$)	92.35	< 87.60	89.14	92.59
P_R (\$)	115.53	< 87.71	114.32	115.54
S_S (\$ mill.)	79.81	< 0.28	68.72	79.83
Optimizing Rule:	max. $S_{RG} + S_{LN}$	$S_{RG} + S_{LN} = 0$	max. S_T	max. S_S

The last market type illustrated in the base case simulation is social monopoly. Social monopoly requires optimal control of both railway pricing and the configuration of the grain transport system. It would not occur without special policy intervention and serves as the standard against which the other market types and various policy measures are evaluated. The optimal grain transport system under social monopoly has the same configuration as under rail monopoly and farmer monopoly. Output and surplus characteristics are similar to farmer monopoly but both are marginally higher under social monopoly. This is because the price paid at the elevator (P_E) is slightly above the railway demand price (P_R), indicating that forcing the railway to operate at a small loss (more than offset by higher S_{RG}) provides a better outcome from the social perspective.

Lower Grain Prices

In Table 2 we examine what happens when grain prices are lower -- that is, P_W is reduced to \$140 per tonne. The farmer monopoly market has a 9-elevator system with 372 kilometres of branchline and maximum truck hauls of 41.4 kilometres. This system is slightly smaller than at the higher grain price modelled in Table 1; the major difference here is that P_E , output, and surplus are all much lower. Cultivation still extends across all the region but output is almost 20 percent smaller, reflecting much lower yields. With perfect competition we have a much larger grain transport system but it is only about one-tenth as large as it was under this market type with higher grain prices.

Under rail monopoly the optimal grain transport system has 13 elevators and 485 kilometres of branchlines. Grain output is 2,610,000 tonnes and social surplus is \$13,630,000. The social monopoly outcome at low grain prices indi-

TABLE 2 Optimal Grain Transport System Simulation Results-Lower Grain Prices

	Farmer Monopoly	Perfect Competition	Rail Monopoly	Social Monopoly
N (no.)	9	> 140	13	9
L_{NW} (km)	372	> 2016	485	372
P_E (\$)	94.71	< 88.24	89.89	95.90
m (deg.)	30	30	24.79	30
r_{max} (km)	41.4	< 10.5	32.9	41.4
NQ ('000 t)	2776	< 2615	2610	2814
AC_G (\$)	89.48	< 87.91	89.00	89.56
P_R (\$)	94.71	< 88.24	94.22	94.73
S_S (\$ mill.)	14.52	< 0.87	13.62	14.54
Optimizing Rule:	max. $S_{RG} + S_{LN}$	$S_{RG} + S_{LN} = 0$	max. S_T	max. S_S

TABLE 3 Optimal Grain Transport System Simulation Results - Higher Trucking Costs

	Farmer Monopoly	Perfect Competition	Rail Monopoly	Social Monopoly
N (no.)	91	> 1007	111	95
L_{NW} (km)	1589	> 5720	1775	1628
P_E (\$)	111.82	< 90.39	95.92	116.60
m (deg.)	30	30	25.63	30
r_{max} (km)	13.0	< 3.9	11.3	12.7
NQ ('000 t)	3191	< 2642	2687	3347
AC_G (\$)	95.04	< 89.22	92.82	95.81
P_R (\$)	111.82	< 90.39	110.18	111.92
S_S (\$ mill.)	53.55	< 3.09	46.66	53.93
Optimizing Rule:	max. $S_{RG} + S_{LN}$	$S_{RG} + S_{LN} = 0$	max. S_T	max. S_S

cates that the 9-elevator system is optimal but that output and surplus would both be larger if P_E were set above P_R .

It will be noted that the relative performance under the four market types is the same at both grain price levels: social monopoly similar to but marginally better than farmer monopoly, perfect competition with a very large branchline/elevator system but low grain output, and rail monopoly with about the same output level as perfect competition but a branchline/elevator system quite similar to those under social monopoly and farmer monopoly. Only under rail monopoly is any of the region's cultivable area left uncultivated. We will see the same relative patterns in the other simulations.

Higher Trucking Costs

The simulation results in the base case (Table 1) showed an optimal system much shorter (except with perfect competition) than the actual branchline system on the Prairies. Since the model region has about 10 percent of the area of the actual Prairie grain-growing region, which has about 1100 grain shipment points, we might expect it to have 110 elevators. Why do our simulations show it with far fewer? One reason for this might be that truck (wagon) costs were much higher relative to rail costs at the time the branchline system was constructed and there have been policy impediments to adjustment of the branchline system.⁷ To explore this possibility, we increase trucking costs by ten times to \$0.75 per tonne-kilometre so as to approximate the costs of farm-to-elevator wagon transport of grain the early 1900's.⁸

Compared to the base case, higher trucking costs mean a larger optimal grain transport system, lower output, and smaller surpluses for all market types except perfect competition. The optimal system under rail monopoly (perhaps the closest to actual market conditions) has 111 elevators and 1,775 kilometres of branchline and a maximum truck haul of 11.3 kilometres. On a per square kilometre basis, these are similar to actual mid-1980s values for the Prairies. A grain transport system designed and operated with these parameters (artificial in terms of contemporary transport technologies and relative modal costs) produces \$26 million less social surplus annually than the base case because higher transport costs are incurred and production reduced.

The simulation result for perfect competition with higher trucking costs shows fewer elevators and a higher r_{max} (more trucking) than the base case. This result is caused by the effect of higher trucking costs in reducing production surpluses, thus making it impossible for the region to support as many elevators as previously. The size of the branchline network (and the number of elevators) is determined at the point where regional production surplus reaches zero, that is, where it has been used up in expanding the branchline network to bring the elevators as close as possible to farmers.

Subsidies, Taxes, and Regulation - Rail Monopoly

In Table 4 we report the results of simulations of various subsidy and tax policy measures in an environment of railway monopoly. The optimization rule for each policy measure is the maximization of transportation surplus (S_T).

7. Railways are not permitted to abandon service on any line without regulatory approval by the National Transportation Agency. Moreover, a large part of the Prairie railway system is exempt by Order-in-Council from even the possibility of abandonment until the year 2000.

8. The main source for this parameter is Lewis and Robinson (1984).

Railway Subsidy. Railway subsidies have taken many forms; here we limit our examination to a 25 percent subsidy on railway costs. As shown in Table 4, output is at almost the same level as the base case (rail monopoly with no subsidy) but the railway builds another 104 kilometres of branchline and the elevator cooperative builds four more elevators. Transportation surplus (not shown) increases by almost \$23 million. Clearly, this type of policy is very profitable for the railway, if it is a monopoly.

Railway Tax. Next we simulate the effects of imposing a 25 percent tax on railway costs. While this policy measure might seem unusual, there is a theoretical justification for analyzing taxes and subsidies as equivalent instruments of government policy. A tax on railway costs creates the same size transport system as the rail monopoly base case. Grain production declines slightly when a tax is imposed. Surplus levels are similar. Given our standard of comparison, the social monopoly market, a tax is preferable to a subsidy under rail monopoly.

Grain Production Subsidy. The effects of a subsidy of \$16 per tonne of grain produced (about 10 percent of P_W) are very similar to the rail monopoly base case in terms of grain production and the grain transportation system but the railway's profits (transportation surplus) increases substantially. In all simulations with this market type, the railway in effect receives any subsidy and pays any tax.

Grain Production Tax. Although a tax on grain production is unfamiliar, this type of royalty is well-known for some natural resource products. A grain production tax of \$16 per tonne leads to a very slight decrease in output and a slightly larger elevator and branchline system. Total surplus (S_S) is slightly smaller and transportation surplus is much lower.

Subsidy on Grain Land. Subsidies based on the use of land to grow grain have been used in Canada. A subsidy of \$25 per hectare has significant effects. Only five elevators are built and the branchline network contracts by almost half. Output is only about one-half the base case level, too. This result may appear counter-intuitive, since we would normally expect that subsidization of an input would tend to increase output, not decrease it by almost one-third from the rail monopoly base case. However, it must be remembered that in the rail monopoly market type, the railway is the only decision-maker and behaves so that it captures as much of available social surplus as possible. In this case the railway reduces P_E (which is possible because grain land is subsidized), thus causing grain yields to fall.

Tax on Grain Land. An alternative policy approach would be a tax imposed on the natural resource input used in grain production. A per

TABLE 4 Summary of Optimal Simulation Results - Rail Monopoly Market Type

	N	NQ (^{'000} t)	P_E (\$)	AC_G (\$)	L_{NW} (km)	r_{max} (km)	S_S (\$ mill.)	S_T (\$ mill.)
Social Monopoly	11	3479	116.64	92.59	431	37.4	79.83	-3.85
Rail Monopoly (base case)	11	2639	90.21	89.14	431	37.2	68.72	65.88
Railway Subsidy	15	2634	89.82	88.90	535	31.8	68.25	88.63
Railway Tax	11	2636	90.20	89.14	431	36.9	68.65	43.26
Production Sub- sidy	11	2639	90.23	89.14	431	37.3	68.73	108.10
Production Tax	13	2628	89.95	89.00	485	33.5	68.28	23.75
Land Subsidy	5	1775	63.87	62.25	230	55.5	34.63	91.77
Land Tax	15	3260	110.21	109.37	534	30.7	78.47	16.12
Regulation (rate = \$40)	1	3129	109.57	94.45	0	124.1	71.13	23.81
Regulation (rate = \$50)	1	2811	99.57	93.30	0	124.1	67.12	49.50
Regulation (rate = \$60)	21	2621	89.41	88.67	667	26.4	67.23	65.28

hectare tax of \$25 on land used for growing grain brings the rail monopoly market type closest to the social monopoly base case. This type of policy intervention increases grain output by over 700,000 tonnes above the rail monopoly base case and creates an additional \$9.7 million in total surplus. The branchline network is larger and there are more grain elevators. Again, this apparently counter-intuitive result is due to the monopoly position of the railway. It maximizes its transportation surplus by raising P_E and causing output to increase through increased grain yields.

Railway Rate Regulation. Railway freight transport of grain has often been provided under monopoly conditions and railway freight rates on grain have often been regulated. The effects of regulation are modeled for railway rates set at \$40, \$50, and \$60 per tonne. The actual average cost of railway transport of grain was about \$37.50 per tonne; the three simulations represent successively less stringent railway regulation.

More stringent railway freight rate regulation (\$40 and \$50 per tonne) causes the railway to serve the region with one elevator located on the mainline. There is no branchline network; farmers bring their grain to the elevator by truck. Compared to the rail monopoly base case, the most stringent regulation (railway rate = \$40) expands output from 2,639,000 tonnes to 3,129,000 tonnes. Social surplus is higher by about \$2.5 million. Regulation at higher rate levels is better for the railway but not for social surplus. At a regulated rate of \$60 per tonne the transportation surplus

will be almost as high as without regulation and the social surplus is lower.

Subsidies and Taxes - Farmer Monopoly

Table 5 presents simulation results for the single farmer (farmer monopoly, no railway market power) market type. The optimization rule is to maximize the sum of locational production surplus and regional production surplus.

Railway Subsidy. Under farmer monopoly, a subsidy of 25 percent on railway costs increases output by 272,000 tonnes above the base case. This occurs because the railway offers a higher price at the elevator to the farmer (P_E), thus allowing a higher intensity of cultivation. The grain transport system expands to 15 elevators and 535 kilometres of branchline. Social surplus is reduced by about \$860,000 but the farmer's surpluses (locational production surplus and regional production surplus) increase by over \$30 million.

Railway Tax. A tax on railway costs reduces output from the farmer monopoly base case and causes a smaller elevator and branchline system. Social surplus is almost \$500,000 lower and the farmers' surplus fall by over \$28 million from the base case. As with the rail monopoly market type, the farmer monopoly in effect pays all taxes and receives all subsidies.

Production Subsidy. A production subsidy of \$16 per tonne leads to the largest output (3,957,000 tonnes) of any policy measure under all market types.⁹ Social surplus is slightly smaller and the branchline and elevator systems are slightly larger than the farmer monopoly base case. Farmer surpluses are much larger.

Production Tax. A grain production tax (\$16 per tonne) reduces output and the extent of the grain elevator and branchline system -- the results are similar to the lower P_W modelled in Table 2.

Land Subsidy. Under farmer monopoly, subsidizing the use of land to grow grain leads to virtually the same outcome in all respects as in the base case except that the average costs of grain production are much lower and farmer surpluses much larger.

9. If our simulations had included a grain price above \$160.75, we would have expected to have simulated a grain output higher than this.

Land Tax. A tax of \$25 per hectare on grain land gives results which are very similar to the farmer monopoly base case. However, AC_G is higher (\$109.77 instead of \$92.35) because the area of cultivation is reduced and the increased intensity of cultivation raises grain growing costs. The burden of the land input tax falls on the single farmer who is required to transfer most surpluses to the government via the tax.

Subsidies and Taxes: Perfect Competition

Table 6 presents the simulation results for the various policy measures with the perfect competition market type (many farmers, no railway market power). The optimizing rule is to bring to zero the sum of locational surplus and the regional production surplus. As was explained earlier, the inequalities mean that the reported simulation results only approach the optimum -- they do not actually reach it.

Railway Subsidy. Subsidizing railway transportation by 25 percent causes an increase in P_E and, thereby, an increase in output of 438,000 tonnes above the perfect competition base case (about 17 percent). The railway branchline system is even larger (>6,710 kilometres) and there are even more elevators (>1,373) than in the base case.

Railway Tax. A tax of 25 percent of railway costs brings the output parameters (NQ , P_E , and AC_G) close to their perfect competition base case values. However, the railway branchline and elevator systems are much smaller (the tax increases the cost of railway transport, making it a less attractive input) and this gives a total surplus of over \$30 million.

Production Subsidy. Subsidizing production leads to a very extensive elevator and branchline system. No farm is as far as 3 kilometres from a grain elevator and the branchline network is almost 8,500 kilometres in length. Output levels are near the base case values but total surplus is negative, around -\$41.5 million.

Production Tax. The results here are somewhat reversed from the effects of a production subsidy of similar size. The branchline and elevator network is smaller than in the base case, output is the same, and the tax generates a surplus of over \$42 million (but this is still far less total surplus than is possible with other market types).

Land Subsidy. Subsidizing land increases the private surpluses available in grain production and encourages the expansion of the transportation sys-

TABLE 5 Summary of Optimal Simulation Results - Farmer Monopoly Market Type

	N	NQ (’000 t)	P _E (\$)	AC _G (\$)	L _{NW} (km)	r _{max} (km)	S _S (\$ mill)	S _G +S _{LN} (\$ mill)
Social Monopoly	11	3479	116.64	92.59	431	37.40	79.83	83.68
Farmer Monopoly (base case)	11	3444	115.53	92.35	431	37.40	79.81	79.81
Railway Subsidy	15	3717	23.88	94.13	535	32.00	78.85	110.58
Railway Tax	7	3171	107.39	91.16	306	46.90	78.20	51.47
Production Subsidy	13	3957	131.54	92.27	485	34.40	76.25	139.57
Production Tax	9	2929	99.53	89.88	372	41.40	75.12	28.25
Land Subsidy	11	3434	115.53	74.93	431	37.40	79.81	139.81
Land Tax	11	3444	115.53	109.77	431	37.40	78.47	19.81

TABLE 6 Summary of Optimal Simulation Results -- Perfect Competition Market Type

	N	NQ (’000 t.)	P _E (\$)	AC _G (\$)	L _{NW} (km)	r _{max} (km)	S _S (\$ mill)
Social Monopoly	11	3479	116.64	92.59	431	37.40	79.83
Perfect Competition (base case)	> 1143	< 2608	< 87.71	< 87.60	> 6106	< 3.70	< 0.28
Railway Subsidy	> 1373	< 3046	< 101.47	< 88.59	> 6710	< 3.30	< 0.04
Railway Tax	> 519	< 2611	< 87.87	< 87.68	> 4054	< 5.40	< 30.52
Production Subsidy	> 2177	< 2608	< 87.64	< 87.55	> 8498	< 2.70	< -41.49
Production Tax	> 317	< 2612	< 87.99	< 87.75	> 3128	< 7.00	< 42.42
Land Subsidy	> 1679	< 1784	< 61.76	< 59.88	> 7440	< 3.00	< -56.65
Land Tax	> 219	< 3265	< 108.58	< 108.29	> 2568	< 8.40	< 60.94

tem. A land subsidy with the perfect competition market type brings production down almost 50 percent from the social monopoly optimum. Grain yields are very low (at < \$59.88 AC_G is the lowest in all the simulations) and there is still a sizeable transportation system. Because of the costs of the subsidy, the negative total surplus is almost \$57 million. The many-farmer situation of perfect competition leads to construction of a larger transport system network and negative social surplus.

Land Tax. A land tax of \$25 per hectare brings this market type quite close to the social monopoly optimum and produces a much better result than the perfect competition base case. The elevator and branchline network is the smallest under all the policies simulated for this market type.

Conclusions

We can infer from the simulations reported in this paper that a smaller branchline system than at present (one with 11 elevators instead of 110) would be optimal. The choice of the optimal grain transport system is, however, conditioned by the market structure, the relative level of modal transport costs, and the world price of grain. Changing the world grain price and trucking cost parameters have the expected results. Lower grain prices cause lower values for most of the variables and reduce the difference between social monopoly and the other market types. Raising trucking costs to their early 1900s level leads to a much larger transport network under all market types, and provides an explanation of why the actual network is so much larger than the contemporary optimum.

The simulations of different policy measures were based on assumptions concerning optimizing behaviour appropriate to the various market types. It is interesting that simulations of three of the four market types lead to transport networks of approximately the same configuration under all policy measures. The exception is perfect competition. In this case, the result is always a very large branchline network with many elevators and very short truck haul distances. It should be recalled that the existence of this market type depends on a cooperative response by the railway in response to requests from many farmers to extend branchlines so that truck hauls (the costs of which are paid by each farmer) are minimized.

The rail monopoly market type is probably the closest to the real world situation. In terms of social surplus, only two of the policy measures analyzed in the simulations give much improvement over the base case rail monopoly outcome. A tax of \$25 per hectare on grain land moves the system quite close to the social monopoly optimum of S_S=\$79.83 million. The second best policy is rate regulation at \$40 per tonne, close to the level of railway average costs. Other measures have virtually no effect or, in the case of land subsidy, a definitely negative effect.

Farmer monopoly, where there is only one farmer, has a base case which comes closest to the social monopoly outcome. However, this may not be an institutionally realistic market type. Subsidies of railway costs and grain production increase both grain output and the size of the grain transport system while taxes of this type have an opposite effect. Subsidizing or taxing grain land leaves production and the transport system unchanged but both have large, opposite effects on farmer surpluses.

For most market types government taxes or subsidies can move the system closer to the optimum but they do not seem to be capable of creating the full benefits of an optimal system. Other policy arrangements deserving further study include the application of public choice theory and methodology to the design of policy for an optimal grain transport system and the possible role of co-operative forms of ownership, particularly co-operative ownership of rail-

way branchlines. Banks (1986) presents information on the evolution of branchline ownership in the United States. Such an arrangement might be a way of avoiding the excessive building of branchlines when there are many grain producers and a passive railway.

Appendix: Parameter Values

The model's parameters were developed using 1985 values for Saskatchewan as representative of the model region. They are summarized in the table below.

	<u>VALUE</u>
World price for grain per tonne	\$ 160.75
Grain growing costs per hectare:	
- fixed	2,667.70
- variable	0.63
Costs of trucking grain:	
- loading costs per tonne	5.50
- cost per tonne-kilometre	0.075
Elevator Costs:	
- fixed cost per elevator node	21,096.00
- variable cost per tonne	11.17
Railway Costs:	
- branchline costs:	
line-related per kilometre	8,388.00
volume-related per tonne-kilometre	0.01
- mainline costs per tonne	32.39

References

- Ash, L.L. and S. Yagar. 1977. "Optimizing of Western Canada's Country Elevator System", *The Logistics and Transportation Review*, 13: 157-169.
- Banks, R.L. 1986. "Prairie Short Line Railways: Concept and Practice," *Canadian Transportation Research Forum Proceedings*. Saskatoon: University of Saskatchewan Printing Services.
- Borins, S.F. 1982. "Western Canadian Homesteading in Time and Space", *Canadian Journal of Economics*, 15: 18-27.

- Canada. *Report of the Commission on the Costs of Transporting Grain by Rail* (Snaveley Commission), 1976. Ottawa: Commission on the Costs of Transporting Grain by Rail.
- Economic Council of Canada. 1988. *Handling the Risks: A Report on the Prairie Grain Economy*. Ottawa: Supply and Services Canada.
- Fleming, M.S and I.H. Uhm. 1982. "Economies of Size in Grain Farming in Saskatchewan and the Potential Impact of Rail Rationalization Proposals", *Canadian Journal of Agricultural Economics*, 30: 1-19.
- Garrod, P.V. and W. Miklius. 1987. "Captive Shippers' and the Success of Railroads in Capturing Monopoly Rent", *Journal of Law and Economics*, 30: 423-442.
- Heaps, T., J.M. Munro and C.S. Wright. 1992. "A Location Model of Grain Production and Transportation", *Annals of Regional Science*, 26: 111-134.
- Kirkland, C.L. 1975. "A Simulated Consolidation of the Grain Handling and Transportation System for a Region of Saskatchewan", *Transportation Research Forum Proceedings*. Oxford, Indiana: Richard B. Cross.
- Lewis, F.D. 1981. "Farm Settlement on the Canadian Prairies, 1898 to 1911", *Journal of Economic History*, 41: 517-525.
- Lewis, F.D. and D.R. Robinson. 1984. "The Timing of Railway Construction on the Canadian Prairies", *Canadian Journal of Economics*, 17: 340-352.
- Mitchell, D.O. and R.C. Duncan. 1987. "Market Behaviour of Grains Exporters", *The World Bank Research Observer*, 2: 3-22.
- Norrie, K.H. and M.B. Percy. 1983. "Freight Rate Reform and Regional Burden: A General Equilibrium Analysis of Western Freight Rate Proposals", *Canadian Journal of Economics*, 16: 325-349.
- Tyrchniewicz, E.W. and R.J. Tosterud. 1973. "A Model for Rationalizing the Canadian Grain Transportation and Handling System on a Regional Basis", *American Journal of Agricultural Economics*, 55: 805-813.
- Zimmerman, M.B. 1979. "Rent and Regulation in Unit-Train Rate Determination", *The Bell Journal of Economics*, 10: 271-281.