OPTIMAL WOOL FLOWS FOR MINIMIZATION OF TRANSPORT COSTS*

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Movements of wool from grower to wool store in Queensland, N.S.W., Victoria, and South Australia are affected by differing State legislation and Section 92 of the Australian Constitution. Taking various arrangements within each State into account, average wool transport costs from wool production areas to selling centres are found. A linear programming technique is then applied to produce an optimal pattern of wool flows minimizing transport costs for all growers.

Transport costs constitute a significant component of wool marketing costs.[1] This paper looks at the existing flows of wool from grower to wool store, to see if, and how, these flows may be improved to minimize total growers' transport costs. Queensland, N.S.W., Victoria and South Australia are almost a self-contained market with respect to wool movement.[2] Since there is no movement of wool from Western Australia to centres outside that State, and there is only a very small amount of movement of Tasmanian wool outside Tasmania, this analysis of wool flows is restricted to these four States.

Wool is transported from property to store in various ways. Today, road and rail are the main contenders for this traffic although in South Australia coastal ships are often used. Table 1 shows the movement of wool into store, by mode of transport. The competition for wool traffic is complicated by institutional arrangements and the Australian Constitution. The effects of these complications differ between States. Legislation and circumstances surrounding transport arrangements in each State are discussed below. This is followed by a description of a linear programming model to find optimal wool flows to minimize total transport costs[3]

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[1] See Malecky, J. M., "Marketing Costs of Australian Wool", *Quarterly Review of Agricultural Economics*, Vol. 14, No. 4, October 1961, pp. 173-181, and May, P. H., "Costs of Marketing Australian Greasy Wool, 1960-61 and 1963-64", *Quarterly Review of Agricultural Economics*, Vol. 18, No. 3, July 1965, pp. 166-174.

[2] See Table 1 in: Australian Wool Board, *Statistical Analysis* No. 46, Melbourne, 1964.

[3] Transportation or spatial models have been used widely in economic applications. See Chuang, Y. H. and Judge, G. G., *Sector and Spatial Analysis of the United States Feed Economy*, Bulletin 699, Agricultural Experiment Station, University of Illinois, February 1964; Judge, G. G., *Competitive Position of the Connecticut Poultry Industry—a Spatial Equilibrium Model for Eggs*, Bulletin 318, Storrs Agricultural Experiment Station, University of Connecticut, 1956; Judge, G. G. and Wallace, T. D., *Spatial Price Equilibrium Analyses of the Livestock Economy*, Technical Bulletins TB-78, T-79 and T-81, Oklahoma State University Experiment Station, June 1959, December 1959, January 1960; King, G. A. and Schrader, L. F., "Regional Location of Cattle Feeding—A Spatial Equilibrium Analysis", *Hilgardia*, Vol. 34, No. 10, July 1963; Logan, S. H. and King, G. A., "Size and Location Factors Affecting California's Beef Slaughtering Plants", *Hilgardia*, Vol. 36, No. 4, December 1964; Pherson, V. W. and Firch, R. S., *A Procedure for Determining Optimum Warehouse Location*, Research Bulletin No. 706, Purdue University, 1960.

TABLE 1

Movement of Wool from Grower to Selling Broker: Approximate Percentages According to Number of Bales Received at Centre

Wool selling centre	Rail	Road	
		Carrier	Growers' own transport
	%	%	%
Brisbane	39	61	
Newcastle	93	7	
Sydney	90	10	
Goulburn	40	30	30
Albury	2	79	19
Ballarat	2		98
Melbourne	38	45	17
Geelong	60	16	24
Portland	20	20	60
Adelaide[a]	36	15	38

[a] In South Australia 11 per cent of wool received into store arrives by ship.

Source: The figures given are based on estimates obtained from the larger stores in each centre, and are subject to variation.

and finally, an analysis of the results of the model is given.

1. *Existing Transport Arrangements*

Queensland

A unique situation exists in Queensland with respect to the long distances often involved in wool movements. The convenience offered by road hauliers in picking up directly from the property is sometimes offset by bad road conditions (especially in wet weather). Also a road tax scheme ensures comparable road and rail charges, so that in some cases graziers prefer to transport their wool by truck to the nearest railhead, and leave the rest to the railways. (The Government has no hand in determining actual road freight charges.) Because of the convenience of direct loading and single handling, however, and also because of concession rates for back-loads of fruit, road hauliers carry the greater bulk of wool moving into store. Only in rare instances does the grazier move his own clip.

Only a minute percentage of Queensland wool moves interstate. Of course, under Section 92 of the Constitution, legitimate interstate movements cannot be controlled by regulation. Thus interstate road movements (e.g. from southern Queensland to Newcastle) may be made relatively more cheaply than intrastate journeys. To meet this competition the Queensland railways quote rates to Brisbane on a lower cost per mile basis for stations situated near the New South Wales border than elsewhere. At one stage, "border-hopping" from Queensland towns to Tweed Heads in N.S.W. and back to Brisbane was quite prevalent. Road hauliers would drive across the border: switch trucks, drivers or simply change licence plates; and proceed back to their proper destination. The claim was, that by making two interstate journeys, the carrier was exempt from intrastate permit fees. Recent rulings in Queensland courts however have upheld that "trade" was not effected on these interstate trips, and hence that Section 92 of the Constitution did not apply. Border-hopping has consequently been virtually eliminated.

New South Wales

Unlike the Queensland arrangement, a relatively high proportion of N.S.W. wool moves out of the State. Approximately one sixth of N.S.W. wool is sold in interstate selling centres. Table 1 shows the large percentage of inter and intra-state traffic carried by the railways. In both this State and Victoria, legislation is such that the railways are protected against "unnecessary competition from road transport".[4] A State Act in N.S.W. authorizes motor lorries to carry goods free of tax for distances up to 50 miles. Where goods are to be transported by road for more than 50 miles, a permit under the Act is required. In the case of wool (and certain other goods) it is the policy of the Department of Motor Transport to refuse to issue permits for these goods—the consignor being required to use the railways. Albury is distinctive in that road transports deliver most of the clips to this centre. Ninety-three per cent of wool sold in Albury is N.S.W. wool, and although the brokers concerned do have special receiving centres across the border at Wodonga, there is some obvious border-hopping at this point.

A grower sending his wool to Albury pays his broker an additional ten shillings per bale to cover the cost of transport to Melbourne after sale. In most instances, this makes the cost of sending wool to Albury equivalent to that of using direct transport to Melbourne. In the latter case, however, the convenience of pick-up from properties by hauliers, and the possibility of back-loading, often ensures relatively cheaper cartage. Further instances of border-hopping are to be found in northern N.S.W. where, for example, hauliers travel to Wallangarra in Queensland, and then back to Newcastle. The position becomes even more complicated when one allows for legitimate interstate movements to Brisbane. To combat this, the N.S.W. Department of Railways has introduced bulk handling arrangements at Moree and Pokataroo where special arrangements with a local carrier are made. These special arrangements provide that wool-growers within a defined area about these towns may be charged a reduced composite freight rate, covering road transport from woolshed to railhead, and rail to Newcastle or Sydney.

A similar arrangement is made with a carrier at Wagga to compete with the flow of Riverina wool to Melbourne and Geelong. Wool may be sent via this carrying firm to Sydney or Goulburn—the rail rate in such cases being half the usual rate. For ordinary shipments to the Goulburn centre, the N.S.W. railways have made special "through freight" provisions. These provide that wool consigned to Goulburn for sale, and sent later to Sydney for export, is charged a rail freight equivalent to the through journey on an uninterrupted basis. Thus the cost of sending wool to Goulburn is the same as that to Sydney, save for a handling charge which is absorbed by the Goulburn brokering firms. For all rail movements there is an over-riding maximum freight charge of $4 per bale.

Victoria

As mentioned earlier, legislation in Victoria is similar to that in N.S.W., save that farmers themselves may transport their own wool freely to any point in the State. Table 1 shows that relatively more wool is

[4] N.S.W. Department of Motor Transport: private communication.

carried by growers themselves to Victorian selling centres than to N.S.W. selling centres. Less than 2 per cent of Victorian wool moves interstate. Albury, of course, is on the N.S.W.-Victorian border, but Victorian growers who could send to this centre prefer to deal directly with Melbourne. The reason is that Albury wool, after sale, ends up in Melbourne anyway, and that transport charges to both centres are approximately equal. The main selling centres in Victoria are Melbourne and Geelong. An arrangement between the brokers in these cities provides that a grower sending his wool to either centre pays only the minimum of the two rail freights concerned. For example: a grower in the north or east of the State who consigns his wool to Geelong is eligible for a rebate, from the brokering firm, of the difference between the freight cost to Geelong and that to Melbourne. Brokers established in one centre, but not the other, initiated the scheme, and those with stores in both ports quickly followed.

Only two sales per year are held at Ballarat. The wool presented at these sales is collected from a very small local area about 25 miles square and is all delivered by the farmers themselves. Since only between 0·01 per cent and 0·02 per cent of the wool sold in the four-State market moves through Ballarat, this centre can be ignored in the following analysis. To help Portland develop, the Victorian railways introduced several special freight rates for south western Victorian stations. Furthermore, a general concession of a 10 per cent reduction in the mileage freight rate was allowed for any wool moving to this centre. To compete with interstate road transport, cheap rates for south eastern South Australian wool were instigated in conjunction with the South Australian railways.

Border-hopping to Portland, Geelong and Melbourne from west and south west Victoria exists, although far more occurs east from Swan Hill along the N.S.W. border. Here again the railways have been forced to reduce their rates, and special rates to Melbourne and Geelong now operate from most northern Victorian stations. The reduction of these rates has also enabled the Victorian Railways to capture a little of the Riverina wool which previously moved directly by road. Some of this wool, from growers who have arrangements with more localized carriers, now moves by road from the property to the nearest Victorian railhead.

An interesting point often revealed in connection with rail cartage in most States is that the freight rates for wool are usually higher than the rates for general goods, reflecting the well-known practice of charging what the traffic will bear. For instance, on a 300 mile haul (on N.S.W. railways) the freight for wool on a tonnage basis exceeds $20, the equivalent freight cost for certain processed goods being in the vicinity of $8 per ton. The same does not apply with road transport.

South Australia

The introduction of new legislation in October 1964, allowing free competition between road and rail freight transport in this State, has forced the South Australian railways to cut wool carrying rates. In many cases the old rates have been reduced by up to 30 per cent, giving South Australia the cheapest wool mileage rates in Australia. To overcome diseconomies of picking up small loads at isolated sidings, special rates for full truck-loads of baled wool have also been introduced. Further, a rebate of 12 cents per bale has been offered to growers who do their own loading of rail trucks. The Commonwealth railways also exist in South Australia, maintaining the main northern line to Alice Springs and the transcontinental line to the west. Most of the wool from the far north and west of the State travels on this system as far as Port Pirie from where it is carried on to Adelaide by the South Australian railways.

Eyre Peninsula wool is either carted directly by road to Adelaide, or by road and ship, or road and rail. Another combined service operates for wool moving from Broken Hill to Adelaide. The Silverton Tramway carries the wool to Cockburn where it is transfered to South Australian rail trucks for the remainder of the journey. Competitive road transport seems to operate mainly from the south east of the State. The reduction in rail rates from this area has been mainly to combat this, but at the same time is an attempt to reduce a movement of wool to the Portland centre. Most of Portland's wool supply, however, seems to be drawn from south western Victoria.

2. *Description of Method*

In the light of the above existing transport arrangements, wool selling centres have been combined into 6 distinct "super-centres". These are: Brisbane; Newcastle; Sydney (incorporating Goulburn); Melbourne (incorporating Geelong, Albury, Ballarat); Portland; and Adelaide.

This super-centre system reduces the analysis to one entailing only port-side centres. Ideally, to find an optimal flow of wool from wool-grower to wool store that will minimize transport costs, one would like to take into account every single growing unit. Clearly, because of lack of data, this is impossible. Instead, a small region known as a Wool Statistical Service (W.S.S.) area, for which figures are readily available, will be used as the basic production unit. The Australian Wool Board's Wool Statistical Service has sub-divided each State into W.S.S. areas. These areas usually correspond to shires or counties, or groups of the same.

Wool which is not bulk-classed and not sold by private treaty can usually be "identified" as being produced in a certain W.S.S. area. (Sometimes it can only be identified as originating from a larger area—a Statistical Division, comprising several W.S.S. areas.) Although using "identified" wool figures does not account for total clip production, over the four States concerned, for 1963-64, the amount of wool identified by W.S.S. area formed approximately 86 per cent of total wool sold. This percentage varied slightly from State to State, being 85 per cent for Queensland, 86 per cent for N.S.W., 79 per cent for Victoria, and 99 per cent for South Australia. The overall percentage, however, is high enough to allow use of identified figures to represent total clip production.

Given the production in each W.S.S. area, one wants to know where wool should be sent to minimize transport costs. Not all growers will use the minimization of transport costs as the criterion for choosing a wool-selling centre. Additional criteria are expectations of prices likely to be realized at various centres, the availability of back-loading, family tradition and personal contact with a broker. In the following, it is assumed that all farmers attempt to minimize their transport costs, so that the discrepancies between optimal wool flows and existing flows may be regarded as a measure of the influence of these other factors (together with straight grower mistakes.)

The model to be used is essentially a linear programming one. It is analogous to the classical warehouse-retailer transportation model in which demands of retailers for certain goods are met from supplies at various warehouses, the cost of moving quantities of goods from warehouse to retailer being minimized. Wool production units, or the W.S.S. areas, now take the place of warehouses or suppliers. Wool sold at the various centres is equivalent to the demands of retailers. To find the optimal flow one obviously requires the actual costs of moving from areas to centres. For a perfect analysis the cost of moving from each area to each centre is required. In many cases this is obviously nonsensical—e.g. wool from eastern N.S.W. is hardly likely to go to Adelaide. The computer programme used for the model incorporates the possibility of such nonsensical flows.[5]

Inherent in the use of any transportation model is the assumption that total quantity demanded equals total quantity supplied. If this is not the case, a dummy variable must be introduced, on either the demand or supply side, to make the assumption valid. Obviously in any season, even over the virtually closed four-State market, the total amount of wool produced need not necessarily equal the total amount of wool sold. The introduction of a dummy variable to represent stocks is not, however, of prime concern here. To ensure the equivalence between total quantity supplied and total quantity demanded, the following procedure has been adopted. First, it is assumed that, with the closed four-State market, the total amount of wool produced equals the total amount of wool sold. Second, total production is represented by "identified" wool production. Sales of wool therefore are sales of "identified" wool only. The volume of wool sold at a given centre is simply the total, over all areas, of the amounts of "identified" wool flowing to that centre.

Movements of wool were evaluated in 100-bale lots,[6] and since the latest W.S.S. figures available were for the year 1963-64, these figures have been used exclusively. For this season, total production (i.e. production of "identified" wool) over all areas was 3,765,900 bales. The amount of wool sold at each centre is given in Table 2.

TABLE 2

Sales of Identified Wool 1963-64 by Super-Centre

Super-centre	100-bale lots	Percentage of total
	No.	%
Brisbane	7,119	18·90
Newcastle	3,355	8·91
Sydney	9,673	25·69
Melbourne	11,660	30·96
Portland	253	0·67
Adelaide	5,599	14·87
TOTAL	37,659	100·00

The percentage pattern of "identified" wool sales revealed in Table 2 is consistent with the pattern of actual sales (i.e. sales of "identified"

[5] The actual computations were made using an IBM 1620 library programme (Transportation Problem—indirect addressing 1620-LM-017) applied to the IBM 1620 computer at the University of Adelaide.

[6] This modification of the data was required to fit the IBM programme. The restriction is slight and of no real significance.

plus non-identified wool) between centres over the past four years. Table 3 shows this.

TABLE 3

Pattern of Yearly Sales Between Centres

Super-centre	1960/61	1961/62	1962/63	1963/64	1963/64[(a)]
	%	%	%	%	%
Brisbane	18·35	17·84	18·35	18·92	18·90
Newcastle	8·73	8·62	8·94	9·33	8·91
Sydney	28·18	26·78	26·95	26·43	25·69
Melbourne	32·83	33·33	32·33	31·82	30·96
Portland				0·67[(b)]	0·67[(b)]
Adelaide	11·91	13·43	13·43	12·83	14·87
	100·00	100·00	100·00	100·00	100·00

(a) Identified wool only; figures as in Table 2.
(b) Portland commenced operations as a full wool selling centre during this period.

Source: Based on data in: Australian Wool Board: *Statistical Analysis* Nos 36, 39, 42, 46, Melbourne.

The total number of W.S.S. areas for the four-State market is 116. By amalgamation in certain regions this number was reduced to 93.[7] North Queensland areas[8] Q1 to Q4 were neglected—no wool being grown in this region, and Queensland areas Q5 to Q17, Q22, Q24 and Q25 were lumped together, wool from these regions being unlikely to go anywhere but Brisbane for sale. Similarly in South Australia, areas S1 to S5 were combined, wool from these areas always being sold in Adelaide.

In determining the cost of transporting a bale of wool from various areas to various centres a knowledge of as many towns as possible within each W.S.S. areas was required. Towns were chosen, as far as was practicable in a random way covering the whole W.S.S. region. The cost to the centre concerned was then found using road and rail figures (sometimes combined services' figures), and an average taken to represent the area-centre cost. The case of farmers using their own transport had to be ignored, since to impute a value for such a cost was virtually impossible. Up to 40 towns per area were used; although in two cases the number was as low as five. No account could be taken of the relative concentration of wool production within an area, such information being unavailable. In this respect the cost figure used from each area may not represent the true average cost over all farmers in that area. It portrays an "average location" cost, rather than an average cost over all farm locations. Table A in the Appendix shows the final cost figures per bale used in the model.

The availability of published data in the form of official railways rates for all States meant that these latter formed the basis of most costs found. Although many road transport firms were approached in order to try and establish definite road rates, response was very poor. Costs for specific road journeys were usually found by inspection of freight dockets re-

[7] The maximum dimensions of the computer programme allowed only 99 suppliers. Since only six selling centres were used, the number of suppliers in this analysis is greater than the number of receivers, contrary to the usual warehouse-retailer formulation.

[8] In describing W.S.S. areas, the State and W.S.S. area number within that State are indicated. For example, Q21 is W.S.S. area number 21 in Queensland, N stands for N.S.W., V for Victoria, and S for South Australia.

ceived by wool stores in the various centres. The only general figures available were supplied by the Master Carriers' Association of N.S.W. and these, as listed in Table 4, were used as a guide in calculating all otherwise unknown road journey costs. They were also used in establishing costs of moving wool from property to railhead where this was applicable. Rates for both one- and two-way journeys were supplied, but the concessions for back-loading were neglected. This was because of the impossibility of evaluating the incidence of back-loading.

TABLE 4

Road Freight Rates for Wool

Miles	Cost per bale per mile in cents
35 to 100	1·7
101 to 200	1·6
201 to 300	1·4
301 to 400	1·3
401 to 500	1·3
501 or more	1·2

Source: Master Carriers' Association of N.S.W.: private communication.

Queensland

Rates from Queensland W.S.S. areas to Brisbane were generally found using rail charges.[9] For areas where rail did not penetrate, or for areas where rail coverage was inadequate, road rates were used. Interstate rates to Sydney and Newcastle for southern Queensland areas were calculated by finding the average road distance to the centres and applying a rate of 0·6 cents per bale per mile. This figure was derived from actual rates to Newcastle from south Queensland towns.

Some "unlikely" costs were evaluated, as specified in Appendix Table A. The label itself really explains what is meant here. Instances of such costs are where wool from a certain area has to bypass one centre to get to another, or where existing road and rail systems do not allow easy movement between area and centre. Examples are the two costs from Queensland areas Q23 and Q27 to Sydney.

New South Wales

Rates to Sydney and Newcastle were found in the same way as Queensland rates to Brisbane.[10] The special arrangements at Wagga and Moree however were taken into account, as were all special rail rates for near-border towns. To find costs to Melbourne and Portland, direct-journey road rates were used in conjunction with road rates to the nearest Victorian railhead and rail the rest of the way. Costs to Brisbane were evaluated using known road transport charges in conjunction with Table 4 figures. Rates to Adelaide were found by assuming road transport to Broken Hill and thence cartage via the Silverton Tramway and South Australian railways.

[9] See Queensland Railways, *Goods and Live Stock Rates Book*, Government Printer, Brisbane, 1961, pp. 147-153.

[10] General rail wool carrying rates may be found in: Department of Railways, N.S.W., *Increases in Merchandise and Livestock Rates*, Government Printer, Sydney, 1962, p. 44.

In general, all rates were determined using information on existing transport arrangements collected in visits to wool stores in the various centres. The rates presented in Appendix Table A are consistent with respect to existing flow patterns in all but two instances. Both these occur in northern N.S.W. They are the costs from areas N1 and N3 to Brisbane. According to the rates found, from these areas one would expect that more wool would be moving to Brisbane than Sydney and Newcastle. In fact, the reverse applies. The first case is relatively unimportant, only approximately 100 bales being involved. The second however is of more significance. A logical explanation lies in the fact that for northern N.S.W. growers, the railways are granting concessions on bulk back-loading of superphosphate from Newcastle.

Victoria

Again, just as in N.S.W. and Queensland, rail rates[11] were used in determining the majority of costs from Victorian W.S.S. areas to the major selling centre, Melbourne. Due to the State's extensive rail network, it was really only for the three most eastern regions in Gippsland and one north eastern area that road rates had to be brought into use. Here, road costs to the nearest rail station were calculated and added to the corresponding rail charges to Melbourne. (By legislation Victorian growers who do not transport their own wool direct to store must send it by rail from the nearest railhead.) The special rail rates to Melbourne mentioned earlier were used, as were the discounted rates to Portland. Interstate rail rates were found to Adelaide, these being competitive with known road transport charges. No costs were evaluated for transport movements to N.S.W. centres however—no wool at present moving this way, and there being no reason to suspect any future change in this arrangement.

South Australia

As explained previously, in this State rail rates[12] are usually determined taking into account corresponding road rates. In only two cases, involving shipping movements from Eyre Peninsula and Kangaroo Island, were average transport costs to Adelaide found by using other than straight rail costs. The costs to Portland and Melbourne were determined using available rail charges and known road freight rates to both centres. Some costs for non-existing flows were introduced (to Portland) and, as in all other States, several were classified as "unlikely".

3. *Analysis of Results*

Optimal wool flows were found using three distinct cost structures. Details of these were:

Structure 1: Costs appropriate for existing wool flows;
Structure 2: All costs;
Structure 3: Structure 2 with deletion of "unlikely" costs.

Table 5 contrasts existing flows and optimal flows for Cost Structure

[11] See Victorian Railways, *Goods Rates Book*, Government Printer, Melbourne, 1964, p. 42.

[12] See South Australian Railways, *Goods and Livestock Rates Book*, Government Printer, Adelaide, 1960, p. 157.

1.[13] The most significant and obvious result shown in this table is that, in all except four cases, the optimal solution results in wool from any given area being sent to only one centre. As a consequence, wool does not necessarily move exactly according to existing patterns. In general, however, the optimal flows approximate existing flows extremely well. The total transport cost in this optimizing arrangement is $11,181,512 which is approximately 98 per cent of the actual real-world total transport cost. The four areas from which production is split are Q21, N37, V23, and S11. The southern Queensland area Q21 is obviously the residual area for adjustment of Brisbane-Newcastle demands. Flows from area N37 in south west N.S.W. and area S11 in south east South Australia have similar explanations. Although the split flow from south western Victoria area V23 is easily interpreted, it is far more interesting than the others. There is enough wool emanating from this area to provide Portland (situated within the area) with its total demand and to have some over to send to Melbourne. Consequently, other areas already sending wool to Portland do not appear as sending wool to this centre in the optimal solution.

The most significant discrepancies between actual and optimal flows using the first cost structure are seen in areas Q21, Q23, N2, N3, N4, N7, N10, N11, N12, N16, N27, N37, V23, S10, S11. Within these 15 areas there seem to be three sub-groups loosely connected by "residual" areas, viz:

(i) Q23, N2, N3, N4, and Q21;
(ii) N7, N12, N16, Q21, and N37;
(iii) N10, N11, N27, N37, S10, and S11.

The first group mainly involves reallocation of flows between Brisbane and Newcastle. The optimal solution suggests that more wool should move from northern N.S.W. to Brisbane and conversely from southern Queensland to Newcastle. This is simply a reflection of cheap interstate transport costs. (Included in this group is area N3, mentioned earlier with regard to superphosphate back-loading from Newcastle.) The second group is a reallocation between Sydney and Newcastle, with Melbourne and Brisbane just brought in also. Lower freight rates to Newcastle from areas N7, N12 and N16 ensure that all wool from these areas is sent to Newcastle rather than Brisbane or Sydney. The third group reflects a Melbourne-Sydney-Adelaide adjustment. The reallocation of all area S10 wool to Adelaide instead of Melbourne, and most of area S11 wool to Melbourne instead of Adelaide occurs for two reasons. The first is that in the optimal solution no wool from area N10 goes to Sydney; instead it is all sent to Adelaide. The second reason is that, although the freight charges to Melbourne from areas S10 and S11 are equal, the rate to Adelaide is smaller for the first-mentioned area, S10. All area N11 wool now moves to Melbourne, reflecting once again lower interstate transport costs, and adjustments for Sydney and Melbourne flows are made via areas N27 and N37. With respect to Victoria, it is interesting to note that, corresponding to existing patterns, no wool from this State moves across its border.

[13] For the three runs on the computer, the average reading-in time was approximately five minutes, actual time of execution of the problem six minutes, and punching-out time two minutes.

TABLE 5

Optimal Wool Flows (100-Bale Lots) for Minimization of Transport Costs using Existing Freight Costs

Prodn. area code [a]	Prodn.	Brisbane		N'castle		Sydney		Melb.		Portl.	Adel.	
Q5–17 22, 24 25	3505	3505	3505									
Q18	283	283	283									
Q19	50	40	*50*			9					1	
Q20	475	475	475									
Q21	461	447	*87*	4	*30*	10	*344*					
Q23	533	527		6	*533*							
Q26	417	417	417									
Q27	466	466	466	0								
Q28	226	225	*226*	1		0						
N1	1			1	1	0						
N2	365	152	*365*	203		10						
N3	942	28	*942*	884		30						
N4	303	183	*303*	103		17						
N5	291	12		268	*291*	11						
N6	586	0		572	*586*	13						
N7	675	216		332	*675*	127						
N8	349	10		303	*349*	36						
N9	1366	81		78		1184	*1366*	21			2	
N10	902	3				141		11			747	*902*
N11	728					112		561	*728*		55	
N12	533	20		308	*533*	205						
N13	595	20		1		574	*595*	0				
N14	531	0				530	*531*	1				
N15	807			1		786	*807*	20				
N16	212			125	*212*	87						
N17	506			5		501	*506*					
N18	241			0		241	241					
N19	916					915	*916*	1				
N20	145			141	*145*	4						
N21	1					1	1					
N22	91					89	*91*	2				
N23	845					838	*845*	7				
N24	487					458	*487*	29				
N25	373					363	*373*	10				
N26	954					890	*954*	64				
N27	429					235	*429*	194				
N28	675					53		622	*675*			
N29	318					45		273	*318*			
N30	884					30		854	*884*			
N31	441					0		441	441			
N32	59					59	59					
N33	130			17		113	*130*					
N34	388	9		1		378	*388*					
N35	326					305	*326*	20			1	
N36	137					137	137					
N37	234					87	*147*	147	*87*			
N38	190					0		190	190			
N39	305					49		256	*305*			
V1	16							10	*16*		6	
V2	31							31	31		0	

TABLE 5 (cont'd)

Prodn. area code [(a)]	Prodn.	Brisbane	N'castle	Sydney	Melb.	Portl.	Adel.
V3	166				165 *166*	1	
V4	107				106 *107*	1	
V5	180				180 180		
V6	141				141 141		
V7	162				162 162		
V8	126				126 126		
V9	415				415 415		
V10	179				179 179		
V11	126				126 126		
V12	81				81 81		
V13	4				4 4		
V14	111				111 111		
V15	230				230 230		
V16	242				242 242		
V17	255				255 255		
V18	425				422 *425*	3	
V19	584				550 *584*	23	11
V20	71				63 *71*	7	1
V21	547				473 *547*	73	1
V22	569				561 *569*	8	
V23	272				197 *19*	75 *253*	0
V24	441				404 *441*	37	
V25	485				484 *485*	1	
V26	284				284 284	0	
V27	35				35 35		
V28	64				64 64		
V29	391				391 391		
V30	244				244 244		
V31	11				11 11		
V32	56				56 56		
V33	128				128 128		
V34	168				168 168		
V35	.17				17 17		
V36	39				39 39		
V37	5				5 5		
S1–5	1683						1683 1683
S6	600				0		600 600
S7	214				6		208 *214*
S8	793				0		793 793
S9	441				1		440 *441*
S10	365				158	0	207 *365*
S11	1150				557 *877*	24	569 *273*
S12	328				54		274 *328*
Demand		7,119	3,355	9,673	11,660	253	5,599

[(a)] Area Code refers to the State and W.S.S. area number, e.g. Q21 is W.S.S. area 21 in Queensland. N stands for N.S.W., V for Victoria, and S for South Australia. An italicised figure indicates a discrepancy between the optimal flow and the existing flow. An entry 0 in the table indicates that although some wool moved between the area and centre concerned, this amount did not exceed 50 bales.

The introduction of new "likely" and "unlikely" costs via Cost Structure 2 provided no significant change in the optimal Structure 1 flows. The only areas from which flow patterns altered were Q21 and N1. The single lot in area N1 went to Brisbane instead of Newcastle. A reverse effect occurred in flows from area Q21, 86 lots from there now going to Brisbane and 31 to Newcastle. Transport costs fell, as one would have hoped, the lower transport cost in this case being \$11,181,323, a reduction of only \$189 on the original optimum cost.

The optimal flows for Cost Structure 3 were identical in every respect to those for Structure 2, "unlikely" costs obviously having been appropriately named. This result implies that the discrepancies between optimal flows for Structure 1 and 2 are due to the introduction of "likely" costs only. From Appendix Table A it is seen that new "likely" costs were introduced in sixteen instances, involving areas N1, N10, N21, N30, N31, N33, N35, N36, N38, V1, V2, V5, V6, V7, V27, S12. Ten of these were to Portland. Because of the position outlined above with respect to Table 5, however, none of these changes had any effect on Portland flows. It is obvious the new cost from N1 to Brisbane was the cause of the above mentioned effects on optimal flows for Cost Structure 2. The remaining five new "likely" costs had no effect anywhere.

In this paper Constitutional effects and effects of State legislation on wool transport movements have been looked at in some detail. An optimal wool flow minimizing total growers' transport costs has highlighted the relative lower cost of interstate movements. This conclusion has prompted a further application of the transport model using a set of wool transport charges that might have existed in the absence of interstate road competition.[14] Where rail authorities have given specific concessions to meet road competition near State boundaries, as described earlier, these concessions were eliminated to produce a hypothetical set of charges. It was not possible to precisely separate these concessions in Queensland so that adjustments to existing charges were made on the assumption that transport costs by rail should depend on mileage travelled irrespective of whether the wool producing region is in southern Queensland, adjacent to the New South Wales border, or in central or northern Queensland where it is not feasible for woolgrowers to send their wool interstate.

The results of this new calculation of optimal wool flows show changes in wool flows as well as in the aggregate expenditure on wool transport by woolgrowers. In the new model no Queensland wool moves interstate whereas in the solution to the first model about 90,000 bales moved from southern Queensland to Newcastle and Sydney. This change in direction of flow is counter-balanced, since capacities at selling centres are fixed, by additional wool flowing from northern New South Wales to Sydney and Newcastle instead of Brisbane. Although more wool from western New South Wales is sent to Adelaide than in the first model, there are only marginal differences in the wool flows between the Riverina and

[14] These calculations follow the suggestion of A. S. Watson of the University of Adelaide that the existing transport charges used in the first application of the transport model partly reflect the extent to which railway authorities can exert monopoly powers. The growth of interstate road haulage has challenged the basis of railway charging especially in the areas close to State boundaries so that it is possible by using the transport model with a new set of charges to estimate the savings in woolgrowers' transport costs in the various States that have followed the new rates.

Victoria. Victorian and South Australian wool behaved as before except that less wool was sent from the south-east of South Australia to Adelaide, balancing the additional supplies from New South Wales.

The changes in aggregate expenditure on wool transport under the first and second model are set out in Table 6.

TABLE 6

Transport Costs of Moving Wool From Producing Regions to Selling Centres in Eastern Australia[a]

$

State	Model based on existing transport charges		Model with concessions to border areas removed		Per cent increase
Queensland	2,892,903	(4·51)	3,028,394	(4·72)	4·68
New South Wales	6,038,174	(3·31)	7,818,171	(4·28)	29·48
Victoria	1,190,728	(1·61)	1,468,980	(1·98)	23·37
South Australia	1,059,707	(1·90)	1,406,976	(2·52)	32·77
Total	11,181,512	(2·97)	13,722,521	(3·64)	22·73

(a) Figures in brackets are average costs per bale.

These results clearly show the reduction of woolgrowers' transport costs that has followed the competition of interstate road transport to the railway systems. However, the amount to which woolgrowers in other regions away from State boundaries and without the option for road transport are subsidizing other users of the rail system has still not been investigated, and without detailed information on the costs of rail and road operations there appears to be no satisfactory way of tackling this problem. In further analysis it is hoped to look at the effect on the original optimal flow of changes in production in supplying areas and changes in storage capacities at various centres.

APPENDIX

TABLE A

Average Transport Costs per Bale between Wool Production Areas and Selling Centres[(a)]

Production area code	Brisbane	Newcastle	Sydney	Melbourne	Portland	Adelaide
	$	$	$	$	$	$
Q5-17, 22, 24, 25	5·28					
Q18	4·99	5·96	6·03			
Q19	4·73	5·64	5·73			6·67
Q20	4·41	4·92	5·42			
Q21	4·31	4·45	4·50			
Q23	3·03	3·06	3·78*			
Q26	3·08	3·54				
Q27	2·50	2·88	3·60*			
Q28	2·40	3·38	4·10			
N1	1·95**	3·98	4·07			
N2	2·09	3·83	4·18			
N3	3·29	3·98	4·37			
N4	3·29	3·76	3·86			
N5	3·92	3·73	4·19			
N6	4·28	2·98	4·00			
N7	3·08	2·75	3·15			
N8	3·93	3·50	3·62			
N9	6·24	4·56	4·56	6·57		6·80
N10	9·04	4·83**	4·60	5·40		3·30
N11		4·68*	4·40	3·80	3·80*	4·50
N12	4·71	3·85	4·11			
N13	5·89	4·07	4·07	6·11		
N14	5·80	4·07*	4·06	5·85		
N15		4·00	3·95	5·23		
N16		3·79	3·87			
N17		4·10	3·50			
N18		3·64	2·48			
N19		4·09*	3·38	4·24		
N20		1·68	2·97			
N21		2·10**	1·10			
N22		3·85*	2·50	3·44		
N23			3·03	3·72		
N24			4·15	4·20		
N25		4·00*	3·99	4·28		
N26		4·03*	3·08	3·55		
N27			2·82	3·07		
N28			2·42	1·92		
N29			3·79	3·28		
N30			3·90	1·78	2·97**	
N31		5·55*	5·15	1·35	2·18**	
N32			3·68			
N33	4·72**	4·17	4·17			
N34	5·17	4·20	4·20			
N35		4·05*	4·05	4·69		6·80**
N36	5·35**	4·07*	4·07			
N37			3·70	3·60		
N38			4·25	1·82	2·50**	
N39			3·92	2·90		

TABLE A (cont'd)

Production area code	Brisbane	Newcastle	Sydney	Melbourne	Portland	Adelaide
V1				2·13	4·43**	2·96
V2				1·80	3·17**	2·58
V3				2·30	2·96	4·18*
V4				1·89	2·93	4·58*
V5				2·27	2·47**	
V6				1·72	2·78**	
V7				1·88	2·70**	
V8				1·86		
V9				1·79		
V10				1·98		
V11				1·65		
V12				2·15		
V13				2·38		
V14				1·55		
V15				1·04		
V16				1·59	2·31	
V17				2·43	2·62	
V18				2·12	1·86	2·98*
V19				1·65	1·27	2·33
V20				1·60	0·88	2·00
V21				1·58	1·01	2·50
V22				1·83	1·73	
V23				1·50	0·56	2·30
V24				1·52	0·88	
V25				1·59	2·17	
V26				0·93	2·38	
V27				2·01	2·61**	
V28				1·22	2·12	
V29				0·69	2·70*	
V30				0·48	2·78*	
V31				0·80		
V32				0·96		
V33				1·72		
V34				2·18		
V35				3·12		
V36				3·13		
V37				3·98		
S1–5						3·46
S6				6·13	4·94*	1·02
S7				5·55	4·37*	1·21
S8				5·70	4·50*	0·83
S9				5·32	4·12*	0·94
S10				2·00	1·36	1·13
S11				2·00	1·12	1·29
S12				4·72	3·87**	0·95

[a] A cost with no superscript attached indicates an existing flow between the area and centre concerned. More or less "unlikely" costs, introduced for reasons explained in the text, are indicated by a single asterisk. Costs relating to movements not at present existing but thought to be worthwhile appraising are indicated by a double asterisk.