

APPENDIX A

CALIFORNIA’S LIVESTOCK INDUSTRIES

The total cattle inventory in California peaked at 5.25 million in 1974 and then declined through 1992. The cattle inventory in 1996 was 4.6 million head (Table A1). Of these, 18% were beef cows, 27% dairy cows, 4% beef replacement cows, 13% dairy replacement cows, and 38% other cattle (mainly steers and calves under 500 lb.).

Table A1: California Cattle by Class, Selected Years¹ (1,000 Head)

Year	Cows that have Calved			Heifers 500 Lb. & Over		Other Cattle			All Cattle & Calves	
	Beef	Dairy	All	Replacements	Other Heifers	Calves under 500 Lb.	Bulls 500 Lb. & over	Steers 500 Lb. & over		
										Beef Cow
1987	970	1,062	2,032	155	470	175	1,068	65	785	4,750
1991	900	1,150	2,050	155	505	185	1,015	70	620	4,600
1996	840	1,260	2,100	160	600	170	950	70	550	4,600

¹ All figures as of January 1.
Source: CDFA (1997)

About 90% of the state’s beef herd has historically been located in four regions—San Joaquin Valley, Central Coast, Northern Mountain and Northern Sacramento. Twenty years ago the dairy herd was located mainly in the San Joaquin Valley and the Greater Los Angeles area (mainly the Chino Valley), but in recent years development and environmental pressures have forced a substantial number of dairies to relocate to the San Joaquin Valley and to other states. Today, the San Joaquin Valley has the largest concentration of both dairy and beef animals in the state, with about 29% of the beef cow herd and 55% of the dairy cow herd.

Table A2: California Cattle Inventory, Supply and Disposition, 1995 (1,000 Head)

Beginning Inventory	Calf Crop	Inshipments	Marketings ¹		Farm Slaughter ²	Deaths		Ending Inventory
			Cattle	Calves		Cattle	Calves	
4,650	1,780	800	2,135	252	18	90	135	4,600

¹ Includes custom slaughter for use on farms where produced, but excludes interfarm sales. ² Excludes custom slaughter for farmers at commercial establishments.
Source: CDFA (1997).

California's calf crop in 1995 was 1.78 million head and inshipments amounted to 0.8 million head. Marketings amounted to about 2.4 million head, 18,000 were slaughtered in farms and 245,000 died (Table A2). California's share of the U.S. calf crop has remained relatively stable over the past 25 years. Although California is a major feedlot state, it is still a net exporter of calves. Approximately 60% of the calf crop is born in dairies rather than cow-calf operations, but the male dairy calves are fed for beef production in feedlots. About 34% of all marketed animals are imported from other states, Mexico and Canada.

The number of cattle and calves marketed from feedlots has fallen consistently from 839,000 head in 1986 to 595,000 in 1995. The severe droughts in California between 1988 and 1994 affected the availability and quality of pastures, reducing the number of finished animals available for slaughter. The number of cattle and calves slaughtered under federal and state inspection also decreased steadily between 1986 and 1993. In 1994 and 1995 the slaughter of cattle increased by 10% while the slaughter of calves jumped from 70,000 head to 196,000 head (CDFFA, 1997).

California dairy cows amounted to 15% and California calves to 16% of the national total slaughtered for each category while steers were only about 2% of the national total (Table A3).

Table A3: Federally Inspected Slaughter in California - 1996

Category		1,000 head	% of U.S. total
Total		1,011	3
Steers		293	2
Heifers		68	1
Cows	all	608	9
	dairy	455	15
	other	153	4
Bulls & Stags		42	6
Calves		268	16
Source: author constructions from NASS.			

California has a large beef deficit. Assuming that per capita beef consumption is at the national average (98.12 pounds per annum in 1995), total annual beef consumption in the state is about 3,238 million pounds. Marketings of cattle and calves in 1995 amounted to 2,704 million pounds live weight (CDFFA, 1997). Assuming a meat yield of 55%, the state's net beef production was 1,487 million pounds—and thus the net beef deficit was 1,751 million pounds. The actual deficit is larger because some of the beef produced is sold out of the state. California's beef deficit is covered with beef imported from other states and Canada.

Despite California's large beef deficit, its large slaughterhouses export to other countries about 20% of their output and an additional 25% is shipped to other states. Integrated firms specialize in supply-

ing Japan and Korea with high value cuts obtained from beef cattle, and less demanding markets with low value cuts. Some slaughterhouses export select cuts from cull dairy cows to Japan while the less valuable cuts are ground and shipped to other states. California beef is sold in retail stores as far as the East Coast. All hides of livestock killed in California are salted and exported, mainly to Japan and Korea.

Movement of livestock

The marketing of beef products has been transformed from local-regional to national-international, while live fed-cattle and feeders still tend to be marketed locally or regionally (Cothorn, 1991). However, it is not uncommon to send cattle either for fattening or milking to other states in response to market circumstances.

The latest comprehensive study of cattle movements into California was conducted in 1989. There have been no studies of cattle movements out of the state or of movements in and out of the state of other livestock species. In 1988, 823,347 feeder cattle and 55,705 lactating cattle passed through California's agricultural inspection stations into the state (Oltmans, 1989). Cothorn (1991) estimated that in the late 1980s about 1 to 1.2 million animals were shipped annually into California, more than 90% for stocking or feeding rather than slaughter. Since California has a large supply of grassland, it is common for operators to buy stocker cattle out-of-state, ship them to California to harvest winter and spring grass, and transport these animals out-of-state for finishing and processing, with the resulting boxed product then shipped to California retail warehouses for distribution and consumption. Heron and Suther (1983) report that one livestock auction yard, selling on average 3,000 cattle per day with 50 sales per year, sold to 120 different owners, and shipped to 25 California counties with high livestock densities as well as five other states.

The movement of feeder cattle into California has a clear seasonal pattern. In 1988, 37.95% of animals arrived in the autumn and 37.13% in winter. Northern California receives seasonal shipments from northern or northeastern states with the onset of winter. The northeastern part of California receives cattle on its ranges east of the mountains in the spring, and also from the colder northern states prior to the onset of winter. The San Joaquin Valley and the central coastal area receive their feeder cattle shipments primarily during the months when there is grass on the range. The feedlots in the Imperial Valley receive feeder cattle during the entire year. About 93% of all inshipments of feeder cattle originated within a distance of 1,000 miles from California's eastern border plus Mexico; almost 80% originated in neighboring states plus Mexico. The imported feeder cattle were consigned mainly to the Imperial Valley (35.82%) and the San Joaquin Valley (31.74%). Smaller shipments went to the Sacramento Valley (14.25%) and to the central coast of California (12.47%) (Oltmans, 1989).

No seasonal variation was found in the movement of dairy cows into the state. However, there is a substantial seasonal variation in the areas receiving dairy cattle, indicating that California dairies

vary their demand for herd replacement (Oltmans, 1989). Most of the imports of dairy cattle into the San Joaquin Valley originated in states east of the Rocky Mountains. The share of lactating cattle moving into the state from within a distance of 500 miles or less was 46.90% while 30.86% traveled between 1,000 and 1,500 miles. No imports of lactating cattle from Mexico were registered (Oltmans, 1989). The imported dairy cattle were consigned mainly to the San Joaquin Valley (63.47%) and Southern California (26.10%). A small number of dairy cattle (3,832 animals) was imported for slaughter, with 91% originating in the states west of the Rocky Mountains (Oltmans, 1989).

Most imports of dairy heifers occurred during the winter and autumn (Oltmans, 1989). Dairy cows imported for slaughter originated almost exclusively in neighboring states. Slaughterhouses in the San Joaquin Valley and Southern California receive most of these imported cull dairy cows (Oltmans, 1989).

Dairy statistics

The dairy industry is the largest agricultural industry in California, with an estimated 1.26 million milk cows and heifers calving on dairies in the state in 1995. Total milk production in that year was 25,327 million pounds, yielding an annual average production per cow of 20,197 pounds. Cash receipts from farm marketing of dairy products during 1995 totaled approximately 3.1 billion dollars (CDFA, 1997). Table A4 shows the main dairy industry economic data used in the I/O model. All monetary values are expressed in 1993 dollars.

The evolution of the dairy industry depends on variables determined both at state and national levels, such as income growth, changes in tastes, population growth, ethnic composition, agricultural policies and technical change. The state's relative isolation and a booming population have generated a steady demand for fluid dairy products. Expansion of the larger cities, however, forced dairies to move away from the metropolitan zones, a process facilitated by better transportation and cooling techniques.

Table A4: Economic Data of the Dairy and Associated Industries Used in the Economic Analysis

	Dairy Farm Products	Creamery Butter	Cheese, Natural & Processed	Condensed & Evaporated Milk	Ice Cream & Frozen Desserts	Fluid Milk
Output Multipliers ¹ (total)	1.62	2.42	2.13	1.88	2.15	2.09
Income Multipliers ¹ (total)	0.83	0.80	0.66	0.74	0.85	0.80
Income Multipliers ¹ (type III)	1.76	4.83	4.04	2.41	2.98	3.27
Employment Multipliers ¹ (total)	15.65	14.70	12.12	10.97	15.64	14.18
Employment Multipliers ¹ (type III)	2.26	7.06	5.70	4.74	3.87	4.73
Industry Output ¹	2,662.09	58.08	1,214.87	327.71	675.65	3,112.36
Domestic Exports ¹	1,202.81	4.82	9.32	17.68	8.17	25.14
Foreign Exports ¹	6.65	1.79	51.79	9.89	96.55	799.19
Total Employment ²	18,439	121	2,582	759	2,732	9,336
¹ In millions of 1993 dollars; ² full time equivalents. Source: M.I.G. Inc.						

Climatic conditions and improved technologies have allowed producers to take full advantage of economies of scale. Due to the higher efficiency of dairies in the West compared to those in the northeastern states it is likely that total milk output in California will continue to grow at the expense of other states (Perez, 1994).

As a consequence of policy, technological and market changes, a dynamic structure of farms and processing plants evolved in which the relative importance of the different production areas varied over time. Between 1965 and 1975, the Chino Valley in Southern California was the largest dairy region in the U.S. Steady expansion of the dairy cow population in the area continued until 1991 when 312,000 cows were reported. Since that time cow numbers there decreased to 289,239 in 1995 (CDFA). In 1995, 23.4% of the state's milk output was produced in Southern California (5.8 billion pounds) by 23% of the state's dairy herd (Table A5). It is expected that the number of dairy farms and cows in the Chino Valley will continue to decrease as environmental and urbanization pressures force dairies to relocate.

The San Joaquin Valley is now the most important dairy area in the state, accounting for 68.2% of all milk produced commercially in the State during 1995 (16.9 billion pounds) and a similar share of the dairy herd (Table A5). The South Valley (Fresno, Kings, Tulare and Kern counties) produced approximately nine billion pounds of whole milk (36.3% of the state total). The rise in cow numbers over the years was caused by a combination of larger operations and more farms. Farms located in the South Valley ship most of their milk to local plants, but a substantial volume of milk is also shipped to plants located as far away as Los Angeles and San Diego. There is also an active movement of milk between plants (Butler and Ekboir, 1995).

Table A5: Selected Statistics of California's Dairy Industry by Districts and Selected Counties, 1996

Location	Total herd	Number of dairies ¹	Average herd	Total Production (thousand pounds)	Average Production per Cow (pounds)
North Coast	32,466	204	159	291,369	15,160
Humboldt	18,587	155	120	257,015	16,889
North Central	36,828	136	271	22,627	17,432
North East	850	1	850	0	0
Sacramento Valley	42,558	208	205	778,193	19,704
San Joaquin Valley	928,205	1,651	562	17,242,816	20,242
Fresno	73,874	114	648	1,483,723	19,947
Kern	41,652	32	1,302	743,627	20,456
Kings	106,018	164	646	1,979,973	20,046
Madera	27,885	57	489	477,985	20,729
Merced	152,700	372	410	3,183,050	20,372
San Joaquin	80,738	179	451	1,629,797	20,597
Stanislaus	156,442	430	364	2,781,071	20,679
Tulare	288,896	303	953	4,963,591	20,142
Central Coast	8,932	25	357	1,031,059	20,390
Southern California	314,263	353	890	5,971,477	19,836
Riverside	116,040	122	951	2,430,710	19,652
San Bernardino	184,635	208	888	3,216,589	19,652
State Totals	1,364,102	2,578	529	25,292,876	20,011

¹ Includes non-pool dairies.

Source: Author construction based on data from Animal Health Branch (CDFA) and CDFA (1997).

It is expected that the South Valley will become the major source of raw milk for the Los Angeles metropolitan area, since it already supplies about 20 to 25% of Southern California's raw milk requirements. However, as the number of cows in the San Joaquin Valley increases, land suitable for large dairy operations is becoming more expensive and scarce. Waste management is also becoming a major problem, forcing imposition of tighter regulations. The combination of potential pollution and scarce land could impose serious restrictions on future expansion of the industry in the Valley. However, even though expansion of the milking herds has already created environmental problems that have forced counties in the area to restrict the location and size of dairies, people familiar with dairying in the region feel that there is still a considerable potential for further expansion (Butler and Ekboir, 1995).

Table A6: California Milk Cow Operations and Inventory Percentage by Size Groups, 1995

1 - 49 Head		50 - 99 Head		100 - 199 Head		200 + Head	
Operations	Inventory	Operations	Inventory	Operations	Inventory	Operations	Inventory
32	0	5	1	9	4	55	95

Source: CDFA, 1997.

California's dairy herd is heavily concentrated in large farms, with 54.5% of the dairies having more than 200 head and accounting for 95% of the total (Table A6). The number of dairies in California declined steadily until 1989, but has increased for the last seven years. The average herd size, however, has been increasing steadily for the last three decades.

Dairies in the South Valley are larger than in the rest of the state, as shown in Table A7. About 28% of those dairies have more than 1,000 animals and account for 58% of the total. The average dairy size in the South Valley, 998 cows, is about twice as large as the average in the northern part of the Valley and the state average.

Table A7: Distribution of dairies and dairy cattle in the South Valley

Herd size	Number of dairies	Total number of animals
0 - 100	26	885
101 - 300	107	23,426
301 - 500	101	40,384
501 - 750	111	69,966
751 - 1000	96	85,582
1,001 - 1,500	90	111,666
1,501 - 2,000	44	77,591
2,001 - 3,000	29	72,545
3,001 - 5,000	11	40,454
5,000 - 10,000	1	8,000
Total	616	530,499

Source: author construction from data provided by Animal Health Branch, CDFA.

All lactating cows in the South Valley and Southern California are housed in corrals. Nearly all dry cows and 75% of heifers are also in corrals. There is a growing trend to keep herd replacement stock in feedlots or in stocker operations separate from the dairy (Shultz, 1994). Still a majority of dairies in the South Valley (60% to 70%) raise their own replacements. The average dairy size on permit applications for new farms in Tulare county in 1993 was 3,074 cows on 629 acres (Butler and Ekboir, 1995).

Every year about one half of dairy calves and one third of the dairy cow herd go to hamburger or veal (Cothorn, 1991). Cull cows provide a variety of products. Hides are salted in California and exported to Japan or Korea. Some of the most valuable cuts (e.g., sirloin) may be exported to Japan or sold in domestic markets, while the rest of the carcass is sold as ground beef. Some slaughterhouses export up to 25% of a cull cow.

In 1997, 20 plants were registered to process milk in the South Valley, 19 in the northern region of the San Joaquin Valley, and 48 in the Chino Valley. During 1995, approximately 16.2% of the total milk fat produced in the state was used in fluid market milk, including fluid whole milk, fluid lowfat milk and fluid skim milk. Fluid half-and-half used 1.0% of the whole milk fat; butter, 30.1%; cheese, including cottage cheese, 41.3%; condensed and evaporated milk products, 1.9%; frozen dairy products, 6.5% and all other manufactured products, 3.0% (CDFA).

The actual milk price received by each farmer in California depends on the prices for the different milk classes determined by the Milk Pooling Branch (CDFA), the fat and solids-not-fat content of each particular shipment, the transportation allowances corresponding to his/her location and quota ownership.¹² The average milk price received by dairy producers results from the interaction of national markets for milk and butter, and the California demand for dairy products.

Beef statistics

In the mid-1990's, California had the sixth largest cattle inventory, tenth largest beef cow herd, and seventh largest fed cattle marketings in the United States (Lawrence and Otto, 1995). Despite major changes in the beef industry, California continues to be a major beef producing state. Table A8 shows the main economic data related to the livestock and meat industries used in the I/O model. All monetary values are expressed in 1993 dollars. Meat processing industries use several types of animals—mainly cattle, hogs, and poultry—and the data on other types are included in the same table with cattle. Cattle provide the largest volume of meat, and in any case the data do not discriminate between the different types of meats being processed.

The number of farmers raising beef cattle in California has dropped after increasing through the early 1980s. The current number, about 25,000, is nearly 30% below the peak in 1981-1983. The

¹² A detailed explanation of the California milk pricing system can be found in Ekboir et al. (1996b)

TableA8: Economic Data of the Cattle and Associated Industries Used in the Economic Analysis

	Ranch Fed Cattle	Range Fed Cattle	Cattle Feedlots	Meat Packing Plants	Sausages and Other Prepared Meats	Leather Tanning
Output Multipliers ¹ (total)	3.03	3.20	1.93	2.25	1.80	1.95
Income Multipliers ¹ (total)	1.37	1.42	0.77	0.60	0.63	0.60
Income Multipliers ¹ (type III)	5.88	6.68	2.99	17.01	2.36	4.11
Employment Multipliers ¹ (total)	58.12	61.47	20.83	21.30	13.79	16.72
Employment Multipliers ¹ (type III)	2.00	2.10	3.34	8.18	3.26	3.02
Industry Output ¹	459.48	435.26	624.79	1,426.84	987.11	84.94
Domestic Exports ¹	206.08	252.54	338.00	6.48	10.62	68.25
Foreign Exports ¹	2.21	3.08	2.41	129.45	1.46	16.63
Total Employment ²	13,301	12,726	3,898	3,714	4,176	471

¹ In millions of 1993 dollars; ² full time equivalents.
Source: M.I.G. Inc.

average herd size increased from 140 in 1970 to 194 in 1995 and fed-cattle marketings per feedlot increased from 4,625 to 15,000 head per year (Lawrence and Otto, 1995).

The San Joaquin Valley is the largest beef area in the state, with over 35% of the total (Table A9). Most livestock operations are located in the foothills, either the Sierra Nevada or the Coastal Range; a few feedlots, however, are located in the Valley.

Table A9: Leading Counties for Gross Value of All Cattle and Calves, 1995 (Percentage of state total)

State total (1,000 Dollars)	Tulare	Imperial	Fresno	Kern	San Bernardino
1,209,521	18	13	9	6	6

Source: CDFA, 1997.

The cattle industry is concentrated in large operations. In 1995, 4.4% of all beef ranches had more than 1,000 head and concentrated 56.0% of the inventory. Meanwhile, 75.6% of the operations with between one and 99 head accounted for only 6% of the state’s herd (Table A10). The smaller beef operations are of particular concern in regard to exotic diseases. Many are backyard operations with very weak bio-security operating close to commercial operations in the South Valley. Additionally, most backyard operations are very difficult to locate because they do not operate on a continuous basis. Due to these characteristics, it is very difficult and expensive to monitor backyard operations; specific programs aimed at them should be studied.

Table A10: California Cattle Operations and Inventory, 1995 (Percentage by size groups)

1 -99 Head		100 - 499 Head		500 - 999 Head		1,000 + Head	
Operations	Inventory	Operations	Inventory	Operations	Inventory	Operations	Inventory
76	6	15	18	5	20	4	56

Source: CDFA, 1997.

The swine industry

California's pig and hog industry is small compared to other agricultural industries in the state. Measured by the total value of production it ranked 63 in 1995, with annual sales of \$38 million (CDFA, 1997).¹³ Table A11 shows the main economic data pertaining to the hog and pig industry used in the I/O model. All monetary values are expressed in 1993 dollars.

Table A11: Economic Data of the Hog Industry Used in the Economic Analysis

Output Multipliers ¹ (total)	1.95
Income Multipliers ¹ (total)	0.89
Income Multipliers ¹ (type III)	2.71
Employment Multipliers ¹ (total)	27.03
Employment Multipliers ¹ (type III)	1.98
Industry Output ¹	72.88
Domestic Exports ¹	41.14
Foreign Exports ¹	6.05
Total Employment ²	659
1 In millions of 1993 dollars; 2 full time equivalents. Source: M.I.G. Inc.	

The industry is heavily concentrated in the San Joaquin Valley. Five counties there concentrate 85% of the state's production (Table A12).

Table A12: Leading Counties for Gross Value of Hogs and Pigs Production, 1995 (Percentage of state total)

State total (million dollars)	Tulare	Merced	Fresno	San Bernardino	Kings
39	62	7	6	5	4
Source: author construction from CDFA (1997)					

The inventory of hogs and pigs in the state increased strongly in the last decade jumping from 145,000 head in 1986 to 255,000 head in 1995 (Table A13). Production increased from 58.4 million pounds in 1986 to 101.8 million pounds in 1993 and fell to 88.6 million pounds in 1995. The average annual slaughter of hogs and pigs under federal and state inspection in the last decade was 1.92 million head.

¹³This value includes only the direct value of hog production and does not include forward and backward linkages.

Table A13: California Hogs and Pigs Inventory, Supply and Disposition, Selected Years (1,000 Head)

Year	Beginning Inventory Dec. 1 (Prev. Year)	Pig Crop		Inshipments ¹	Marketings ²	Farm ³ Slaughter	Deaths	Ending Inventory Dec. 1	Av. Price \$/100 Lb.
		Dec.- May	June - Nov.						
1986	145	133	131	21	250	14	16	150	52
1990	140	167	191	44	310	20	17	195	58
1995	255	223	199	40	413	24	40	240	40

¹ For feeding or breeding, excludes stock brought in for immediate slaughter.

² Includes custom slaughter for use on farms where produced and State outshipments, excludes interfarm sales.

³ Excludes custom slaughter for farmers at commercial establishments.

Source: CDFA, 1997.

The sheep industry

The value of sheep and lamb production in California in 1995 was \$56 million. Measured by its value, the industry ranked 54 among California’s agricultural industries. The main purpose of the flock is meat production with wool as a by-product. Wool production in California is relatively small; 690,000 sheep and lambs were shorn in 1995, producing 5.25 million pounds of wool with a total value of \$5.36 million.

Table A14: Economic Data of the Sheep, Lambs and Goats Industry Used in the Economic Analysis

Output Multipliers1 (total)	2.51
Income Multipliers1 (total)	1.03
Income Multipliers1 (type III)	4.44
Employment Multipliers1 (total)	36.09
Employment Multipliers1 (type III)	2.37
Industry Output1	72.88
Domestic Exports 1	41.14
Foreign Exports 1	6.05
Total Employment2	38.98
1 In millions of 1993 dollars; 2 full time equivalents.	
Source: M.I.G. Inc.	

Table A14 shows the main economic data referring to the sheep, lamb and goat industries used in the I/O model. All monetary values are expressed in 1993 dollars. Even though goats are not analyzed in this study, the data provided with the I/O model do not discriminate between sheep and goats.

The largest concentration of sheep in the state is recorded in the South Valley (Table A15). However, the location varies with the season and state of pastures. In summer and fall sheep move into alfalfa fields and unfenced pastures in the South Valley; in the winter they move to pastures in northern California or the Imperial Valley, or to other states.

Table A15: Leading Counties for Gross Value of Sheep and Lambs, 1995 (Percentage of state total)

State total (1,000 Dollars)	Kern	Solano	Imperial	Fresno	Merced
56	22	15	12	7	4
Source: CDFA, 1997.					

Sheep in the foothills do not share grazing areas with cattle. These migrant flocks have about 800 ewes. A large number of lambs is shipped from out of state into feedlots in the Imperial Valley. In addition to these large migrant flocks, there is a large feedlot (over 10,000 lambs) in Bakersfield and hundreds of small resident flocks with 50 to 200 ewes. Finally, many sheep are raised by children in youth programs.

Table A16: California Sheep and Lambs Inventory, Supply and Disposition, selected years (1,000 Head)

Year	Beginning Inventory Jan. 1	Lamb Crop	Inshipments	Marketings ¹		Farm Slaughter	Deaths		Ending Inventory Jan. 1
				Sheep	Lambs		Sheep	Lambs	
1986	1,065	630	198	111	685	24	43	50	980
1990	1,000	535	260	144	566	8	32	30	1,015
1995	1,060	380	380	120	649	5	29	17	1,000
¹ Includes custom slaughter for use on farms where produced, but excludes interfarm sales within the state.									
Source: CDFA, 1997.									

Even though the reported size of the sheep flock has varied little over the last decade, (Table A16), the lamb crop fell by about 40% and inshipments rose by 52% (CDFA, 1996). Such a substantial reported change in the state’s flock should be suspected because it would indicate a very large change in the efficiency of the flocks, and could be the result of a reporting error.

APPENDIX B

KEY PARAMETERS OF THE EPIDEMIOLOGICAL MODEL

The key disease parameters for the model are:

- *Incubation and latent period.* The incubation period for FMD has been found to be 4 to 14 days between farms; virus excretion will commence 1 to 5 days before the appearance of lesions (Garner and Lack, 1995). Since the model uses half week periods, it is assumed that any herd coming into contact with the virus will be latent for one period and infectious the following period.
- *Infectious period.* The infectious period has been found to be correlated with type and herd size, husbandry practices, and whether the disease is allowed to run its course, or whether controls are applied lesions (Garner, 1992; Donaldson, 1994a; Sanson, 1994; Sellers and Daggupaty, 1990; Willeberg et al., 1994). If depopulation is not applied, the infectious period for cattle can last between one and nine weeks; for pigs, between 10 to 17 days. If depopulation is applied on the same day the disease is diagnosed or the next, the infectious period can be expected to last four days.
- *Immune period.* If stamping-out is the policy to be applied, the immune period is not important. All infected animals become immune one to two weeks after being infected. If vaccination is applied, herd immunity decreases slowly through births and replacements.
- *Dissemination rate.* The dissemination rate represents the average number of farms per time period to which the virus is transmitted by one affected farm, regardless of the state of the farm receiving the virus—the contact being sufficiently close that disease transmission can occur. Whether the virus results in a new infection depends on the state of each receiving farm. Contact is used in its broadest sense and applies to all routes through which the virus can be transmitted from one herd to another. The dissemination rate depends on environmental factors (landscape, herd density, weather, etc.), type of farming (intensive production, husbandry, fomite opportunities), animal movements (marketing, pasture seekings), farmer behavior (movements, prevention measures), and the control strategy (stamp-out, vaccination).

A hog producer in the South Valley known for his deficient bio-security practices was selected as the index farm for the construction of the epidemiological model. Twenty dairies and hog operations were identified in a three mile radius circle centered on the index farm, and 40 facilities were located within five miles of it. Feedlots were not included in the count due to a lack of geographical information.

Considering that the climatic conditions permit airborne diffusion almost every day of the year, and that the virus is carried in puffs by the wind, it was estimated that large dairies and feedlots would have six effective contacts per week due to airborne diffusion, small dairies would have four effective contacts, large pig operations would have ten, and backyard operations would have one. This number of contacts is maintained until the premises are depopulated. This is probably an underestimation of the true number of contacts since the massive amounts of virus excreted by the large herds in the South Valley would have the potential to infect beyond five miles. Determination of the real importance of airborne diffusion is beyond the scope of this study. However, due to the importance of the issue, it should be researched further.

Movements of animals, people and equipment out of premises with susceptible animals in the South Valley, analyzed in Chapter 4, suggest that the dissemination rates used in previous studies do not reflect the intense production conditions of the South Valley. The number of effective contacts due to all other factors except weather in the first two weeks of the outbreak was estimated to be 10 per week for large dairies, four for feedlots, six for small dairies, six for large pig operations, and zero for backyard operations. This latter figure reflects the fact that these producers have very little contact with commercial channels so it is assumed that the disease spreads from the index farm by air. For comparison, dissemination rates at the start of an epidemic used in European studies range from 2.5 to 4.5 herds per week (Dijkhuizen, 1989; Berentsen et al., 1992b). The range used by Garner and Lack (1995) is 0.5 to 5 herds per week. The dissemination rate can be determined exogenously (as in most studies, including this) or endogenously, by the formula in Garner (1992).

Usually the dissemination rate decreases gradually as a result of transportation bans and increased awareness among farmers (Miller, 1979). Application of quarantines, movement restrictions, and producers' greater awareness slow the spread of the disease and are reflected in the model by a progressive reduction in the dissemination rate. These interventions are assumed to be imposed at different dates depending on the efficiency in diagnosing the first case and resource availability to enforce movement restrictions. It is highly unlikely, however, that the quarantines will be efficient enough to eliminate all dangerous contacts.

The dissemination rates for each half week period and each type of production unit are shown in Table B1. The estimated dissemination rates are significantly higher than those found in similar reports, reflecting the intensive production practices in the South Valley and the high density of susceptible animals. In order to evaluate the sensitivity of the simulations to these extremely high dissemination rates, a second set of runs was conducted with the highest dissemination rates found in the literature. ("Published rates.")

Table B1: Dissemination rates used in the simulations

Estimated rates					
week	large dairies	small dairies	feedlots	large pigs	backyard pigs
0	8	5	5	8	1
1-1	8	5	5	8	1
1-2	8	5	5	8	1
2-1	8	5	5	8	1
2-2	8	5	5	8	1
3-1	5	4	4	5	0.50
3-2	5	4	4	5	0.50
4-1	3	2	2	3	0.20
4-2	3	2	2	3	0.20
5-1	1	1	1	1	0.20
5-2	1	1	1	1	0.20
6-1	0.35	0.35	0.35	0.35	0.20
6-2	0.35	0.35	0.35	0.35	0.20
7th week and beyond	0.25	0.25	0.25	0.25	0.20
Published rates					
0	3	2.50	2.50	3	1
1-1	3	2.50	2.50	3	1
1-2	3	2.50	2.50	3	1
2-1	3	2.50	2.50	3	1
2-2	3	2.50	2.50	3	1
3-1	1.50	0.75	0.75	1.50	0.50
3-2	1.50	0.75	0.75	1.50	0.50
4-1	0.75	0.35	0.35	0.75	0.20
4-2	0.75	0.35	0.35	0.75	0.20
5-1	0.50	0.35	0.35	0.50	0.20
5-2	0.50	0.35	0.35	0.50	0.20
6-1	0.35	0.35	0.35	0.35	0.20
6-2	0.35	0.35	0.35	0.35	0.20
7th week and beyond	0.25	0.25	0.25	0.25	0.20

The transition matrix

Transition probabilities can be presented as a matrix. Each row shows the probability of being in any particular state in the next period when the system is presently in one specific state.

	Susceptible _{t+1}	Latent _{t+1}	Infectious _{t+1}	Immune _{t+1}	Depopulated _{t+1}
Susceptible _t	remaining susceptible	latent infection	0	effective vaccination	natural culling
Latent _t	0	incomplete contact slaughter	infectious	0	contact slaughter
Infectious _t	0	0	ineffective diagnosis	0	infected slaughter
Immune _t	decreased immunity	0	0	remaining immune	natural culling
Depopulated _t	restocking	0	0	0	remaining depopulated

Since all individuals have to be in one of the states in the next period, all rows add up to 1. The expected number of herds in each state in period $t+1$ is obtained as

$$E(x_{t+1}) = x_t A_t$$

where x_t is a row vector showing the number of individuals in each state in period t and A_t is the transition matrix. The path of the epidemic is simulated by repeating this exercise for several periods.

The most important transitions in this study are:

- *Susceptible to susceptible*: This probability is estimated as a remainder after the other probabilities have been calculated. It depends on the spread of the disease, the efficiency of vaccination (if it is used) and the speed of depopulation. Since this is the pool where new infections start, it represents the potential of the disease to continue for another period.
- *Susceptible to latent*: This depends on the number of effective contacts between infectious and susceptible herds in the previous period and the magnitude of the outbreak. This probability (p_{it}) in a particular period is a function of the fraction of infectious farms in the previous period (f_{it-1}) and the dissemination rate (dr)

$$p_{it} = 1 - \exp[-dr_{t-1} f_{it-1}]$$

- *Latent to infectious*: If they are not killed before, it is assumed that all herds become infected after being challenged. This transition depends also on the control policies, the availability of resources to promptly depopulate exposed premises, and the efficiency of diagnostic and depopulation programs. It takes the value 1 if only infected herds are depopulated, and the value 0 if all contact herds are also eliminated. It could take values in the range 0-1 reflecting different depopulation policies and efficiency of the programs.
- *Latent to depopulated*: This probability represents the slaughter of dangerous contacts. It depends on the control policy, the severity of the outbreak and the availability of resources for a speedy depopulation. Since depopulation of infected premises has the highest priority, dangerous contacts can only be killed if enough resources are available.
- *Infectious to depopulated*: This depends on the control policies and the efficiency in identifying and removing infected herds. If the diagnosis is efficient and there are enough resources to depopulate all infected herds in the same period, this transition is equal to 1; otherwise it is equal to the share of herds depopulated in the period.
- *Infectious to infectious*: If the authorities are less than 100% effective in identifying infected herds in the first period or if depopulation of infected herds cannot be accomplished in the same period they are diagnosed, some herds will remain infective in the following period. Two alternatives were considered: 5% and 10% of the infectious herds remain for at least a whole week. This transition is equal

to 1 minus the value of infected to depopulated.

- *Susceptible to immune*: If prophylactic vaccination is considered, this probability shows the efficiency of the vaccination campaign, which depends on the potency and adequacy of the vaccines, as well as the availability of trained personnel for vaccination. If vaccination is not considered, this transition is set to zero.
- *Depopulated to depopulated*: Any depopulated premise remains in that state until the quarantine is lifted. The value of this transition is 1.

Some of the transitions are set to zero because they are relatively small. Neglect of relatively unimportant characteristics of the process allows better identification of the main forces driving the simulation and generally yields more stable results. Some of the transitions that are set to zero in this model are:

- *Susceptible to culled*: This represents the probability that a non-exposed herd will be culled. The only possibility for a whole herd to be culled in normal times is that the farms ceases operations (a very unlikely option since most animals would probably be sold). It is assumed that during a FMD outbreak, no susceptible herds can be culled because of binding restrictions to the regional slaughter capacity.
- *Latent to latent, latent to susceptible and latent to immune*: All these transitions are zero because all latent herds become infectious in the next period, or are depopulated.
- *Susceptible to infectious*: This transition is zero because a premise can become infectious only if it was latent in the previous period.
- *Immune to susceptible*: This depends on the period of immunity and the control strategy (because it depends on whether the immunity comes from vaccination or recovery). Since the only policy is stamping-out or vaccination followed by depopulation of vaccinated animals, the animals in this category are not allowed to lose immunity.
- *Infectious to susceptible*: Infected cattle remain immune against homologous virus for at least three years. Since all infected animals are killed immediately after diagnosed, no infected animals become susceptible again.
- *Infectious to latent*: Same as above.
- *Immune to latent*: Even though herd immunity starts to decrease almost immediately after vaccination through births, it is assumed that the outbreak is controlled before the number of births is large enough to make a significant impact in the health status of the herd. Since healthy animals are not allowed into the quarantine area (except for direct slaughter), they cannot be challenged by the FMD virus.

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- *Depopulated to susceptible*: This is because depopulated premises cannot be repopulated until the quarantine is lifted.
- *Depopulated to latent*: Empty premises cannot become infected with the virus.
- *Depopulated to infectious*: Empty premises cannot become infectious.

APPENDIX C

KEY PARAMETERS OF THE ECONOMIC MODEL

The economic model uses the results of the epidemiological model to estimate the direct, indirect and induced economic impact of a FMD outbreak. Because it is assumed that the outbreak is eliminated in a relatively short period of time (about three months, depending on the date of the initial diagnosis and the eradication strategy), all domestic effects are felt within one year while international trade restrictions continue for two years after elimination of the last outbreak. Since the epidemiological model estimates the number of affected herds, it is necessary to convert these figures into lost output. This is done by multiplying the number of depopulated herds by the average weekly output (milk or meat) for the South Valley and the number of weeks the premises remain empty.

An I/O model is used to calculate the total (direct, indirect and induced) effects on output generated by the direct impact. The I/O model used in this study (IMPLAN I/O system developed by M.I.G., Inc.) was originally developed by the USDA Forest Service in cooperation with FEMA and the Bureau of Land Management to assist the Forest Service in land and resource management planning. IMPLAN closely follows the accounting conventions used in the “I/O Study of the U.S. Economy” by the Bureau of Economic Analysis and the rectangular format recommended by the United Nations.

Since FMD is not considered to be a public health problem for humans, all costs arise exclusively from disruptions of the food-production system.

Economic losses due to a FMD outbreak are split into four categories: (1) the expenditures in extra resources used as a consequence of the disease, whether they are private (drugs, veterinary services, etc.) or public (quarantine enforcement, depopulation, C&D, etc.), (2) the direct effects of the disease on the production system (lost production, animal deaths, lower prices, etc.), (3) the indirect and induced effects of the disease on the entire economy (lost employment, disruption to other industries linked directly or indirectly to the dairy and livestock industries in the infected area, etc.), and (4) losses caused by trade restrictions.

The magnitude of the losses is expected to vary with the time of the year and the nature of the affected premises. Seasonality in milk production and feedlots is relatively small (less than 15%). Seasonal effects should be larger for cow-calf operations and stockers. However, due to lack of information on movements of beef cattle, it is not possible to estimate seasonality effects in cow-calf and stocker operations. Because the annual variation in the two most important sectors—milk production and feedlots—is relatively small, it is ignored and all production effects are calculated based

on annual averages. Seasonality also affects the dissemination rate, because climatic conditions for airborne dispersion are more favorable in winter. However, the higher humidity and lower solar radiation during the winter, which favor airborne diffusion, are partially compensated for by the higher rainfall. Estimation of the magnitude of these effects is beyond the scope of this work. Consequently, seasonal differences in the dissemination rates are ignored.

The estimates of the direct costs of dealing with the outbreak (depopulation, quarantine enforcement, C&D costs, etc.) are based on APHIS (1991) and past experiences of C&D using market prices of December 1997. Since no medicines are used to fight FMD, it is assumed that producers do not spend any additional resources as a consequence of the outbreak. All eradication and C&D costs are born by the state and federal governments, with the exception of compensation for destroyed animals and products which is paid entirely by the federal government. Values for the latter are based on the average market price for similar products in California in December, 1997.

The total value of lost production is shared by producers and the federal and state governments. Producers lose the income from forfeited production during the time the premises remain depopulated, while the federal and state governments lose tax revenue due to the reduced output. The losses suffered by local governments are not included in the calculations.

The method of carcass disposal used can impose heavy costs on particular sectors of society. If the carcasses are buried, the soil above the trenches cannot be disturbed for a long period of time—about 25 years—and for all practical purposes, this land is lost for production. It is unclear whether dairies in which the destroyed animals are buried would still comply with county regulations for solid waste disposal, since manure cannot be incorporated into the soil above the trenches. If the carcasses are disposed of in landfills, a cost is imposed on the counties because of the accelerated filling of the landfill. Estimation of these costs requires a number of assumptions on the future use of the land, or future technologies for garbage disposal, which are beyond the scope of this study. Even though these costs are not included in the calculations, they could be significant and deserve further investigation.

The cost estimates do not include price effects on domestic supplies and demands. Assuming that the outbreak can be eradicated promptly—in less than six months—farmers are not expected to change their long term productions plans. The short term supply of beef will undoubtedly grow as exposed farms are depopulated, then fall until infected premises can return to production. Supply should return to normal levels as production recovers in the affected areas. If consumers recognize that FMD cattle can be safely consumed by humans, domestic consumption should initially rise in response to the fall in prices induced by the larger supply, and decrease when supply contracts as the herds are rebuilt. All these short term effects are extremely difficult to model. It is also expected that the net price effect after the markets return to equilibrium should be small as the initial larger supply is followed by a smaller output. Consequently, these short term adjustments are not considered in the model. Even though the net price effects are expected to be small, the distributional effects can be

large because new suppliers can capture a share of the market during the quarantine period, and it may be difficult for producers in the state to return to their original production levels.

The cost per hour for each type of worker in the C&D crews was obtained from Mace and Yoder (1997). Heavy machinery is used to remove the manure from the corrals, haul carcasses and materials to be burned, and dig trenches to burn or bury the carcasses. It is assumed that the same equipment is used in all premises except backyard operations, but the time requirement depends on the number of carcasses to be destroyed. Heavy equipment is used for three days in small dairies (500 head) and commercial hog operations (500 head), for six days in large dairies (2,000 head) and for nine days in feedlots (15,000 head). Condemned animals have to be fed until they are killed. It is assumed that feed stockpiled on the premises—also intended to be destroyed—is used for this purpose. The government compensates farmers for this feed.

The C&D crews for processing plants are composed of 13 coordinators, 50 operators of machinery and 80 ground cleaners. These crews work for 10 days on each plant. It is assumed that the C&D cost of milk processing plants and slaughterhouses is equal. The total cost of C&D at a processing facility is assumed to be \$390,277, for both slaughterhouses and milk processing facilities.

The dairy industry

Direct losses in dairy production result from the depopulation of infected and contact herds during the quarantine period, which is 60 days after eradication of the last infected herd. The lost milk output is estimated as

$$LM = MP \times INF \times T / 365$$

where MP is the annual milk production in the South Valley, INF is the proportion of infected premises in the South Valley, and T is the number of days that the herds are out of commercial production divided by the number of days in one year. It is assumed that processing plants in the quarantine area have enough capacity to process all milk into fluid milk and cheese. Fluid milk is consumed in the region while cheese can be exported to other states and countries. It is also assumed that all dairies return to normal production one week after the quarantines are lifted. Even though this scenario is unlikely if the number of depopulated premises is large, the estimates provide a lower bound for the losses.

The total value of depopulated herds depends on their quality and composition. It is assumed that the herds are composed only of milking cows, which are valued at the average price for this type of animal in the South Valley. The value of calves and heifers is not included in the calculations because many dairies do not have them on the premises and for those that do, they represent a minor value compared to the cow herd. However, the value of destroyed calves and one year heifers is included in the estimation of the losses of the beef sector.

All contaminated materials in the dairies that cannot be disinfected must be destroyed. The most valuable items in this category are the stocks of hay and corn silage. Since dairies usually stock hay and silage for one year at the end of the harvest season, the volume to be destroyed depends on the timing of the outbreak. It is assumed that the stock is enough for six months of normal operations. It is also assumed that the dairies carry a stock of concentrates enough for one week of normal operation. The annual feeding requirements for an average cow in an average dairy in the South Valley were estimated in Butler and Ekboir (1995). These estimates were adjusted to the proper time intervals, six months for hay and one week for concentrates. The total value of the feed destroyed was obtained by multiplying the feedstock per cow by the number of animals on the premises.

It is assumed that C&D for a large dairy (2,000 milking cows) requires 10 days; for a small dairy (500 milking cows), five days. The cost of C&D and depopulation of a large dairy amounts to \$3,098,279; for a small dairy, \$819,217. The breakdown of the costs is:

	Large dairy	Small dairy
C&D	\$ 136,740	\$ 82,246
Destroyed feed	\$ 561,538	\$136,971
Destroyed animals	\$2,400,000	\$600,000
Total	\$3,098,279	\$819,217

The meat industry (beef and pork)

Losses in the meat industry arise from (1) depopulation of latent and infected premises, (2) destroyed materials, and (3) production lost in the period between depopulation and when reintroduced animals are ready for slaughter. It is assumed that exposed herds are slaughtered and diverted to human consumption. Even though all exports of beef from California would be halted, it is assumed that the markets in the quarantine area can absorb all the beef produced.

It is assumed that meat production falls in equal proportion to the number of slaughtered herds in the state's cattle and pork population. It is also assumed that all ranches return to production as soon as the quarantines are lifted, 60 days after depopulation of the last infected premise. This assumption is reasonable for all livestock premises except for cow-calf operations, which must first rebuild their stock of cows. If stockers are available outside the quarantine area, feedlots should be able to start selling finished cattle between 120 and 150 days after repopulation.

It is assumed that at the time of the outbreak feedlots have hay for half a year of normal operation, and a stock of other feed for a month. It is assumed that C&D of a feedlot (15,000 head) and a commercial hog operation (500 head) requires five days in both cases. The cost of C&D and depopulation of a feedlot amounts to \$14,543,473 while for a commercial hog operation it adds up to \$172,916. The breakdown of the costs is:

	Feedlot	Commercial hog Operation
C&D	\$ 134,780	\$ 92,916
Destroyed feed	\$ 908,693	\$ 25,000
Destroyed animals	\$13,500,000	\$ 55,000
Total	\$14,543,473	\$172,916

The C&D cost for a backyard operation is estimated at \$32,443, since it only requires one day of cleaning by hand, equipment and supplies, and compensation for the destruction of one pig (\$110).

Quarantine enforcement and trade losses

The quarantine cost is calculated on the basis that 300 checkpoints are established in the quarantine area. Two C&D crews, each with a site coordinator and five employees, work at every checkpoint. On average, each checkpoint uses 1,000 gallons of disinfectant per day. The quarantine is enforced for 120 days after depopulation of the last infected or exposed premise. The estimate does not include the cost due to the participation of law enforcement personnel.

Should the Asian markets close due to FMD, the U.S. would have to find alternative outlets for its meats. The obvious alternatives would be to expand the domestic market by reducing imports and/or to expand sales in the FMD-endemic segment or in FMD-free countries that accept the regionalization principle. California imports are mainly manufacture quality while exports to the Far East are both high quality cuts and manufacture beef. American exports to FMD-endemic markets, mainly Russia, are low quality cuts. The change of international beef flows would force a realignment of beef prices to clear the markets. The obvious changes would be an increase in the price of high quality beef in the FMD-free segment, due to the reduced supply, and a fall in the beef price in the U.S. and the FMD-endemic market. An econometric estimation of the price changes required to clear the markets is beyond the scope of this project. Ekboir et al. (1996a) developed a simple model to estimate changes in international beef markets caused by changes in trade patterns. According to that model, the price of U.S. beef exports of manufacture quality would fall by almost 50% if all American beef were sold in the FMD-endemic market. The reduction in the price of high quality cuts received by U.S. exporters should be larger because no other country demands a quality similar to Japan or Korea.

In an optimistic scenario, the markets lost in the FMD-free market would be easily replaced by other foreign markets or by an expansion of the domestic market, due to the lower price of beef. In such a case, the value of all U.S. beef exports would fall by 50% and the loss to the U.S. would be about \$1.3 billion for each year that exports are excluded from the high price market.

Use of input-output model

This study estimates the total cost of a FMD outbreak with an I/O model, for several reasons:

- An I/O model estimates the outbreak's impact on the whole state economy, while a welfare analysis

can only deal with a limited number of sectors. The gains from specifying more detailed responses in the markets included in the welfare analysis are offset by the loss of neglecting several important linkages.

- Estimation of supply and demand functions for the different types of livestock and dairy products involved in the study require substantial amount of data. In addition, beef supply functions must be derived from dynamic decision processes. Static specifications impose strong restrictions about the behavior of animal populations and farmers' expectations biasing the results.
- It is assumed that the outbreak is completely eradicated within a short period of time (about three months); the quarantines would remain for at least two months after depopulation of the last infected premise. Since implementation of changes in production plans in the livestock industry usually take longer than the eradication of the outbreak, it is expected that beef producers who are not infected will not change their production plans.
- The response of consumers to the outbreak cannot be determined in advance. Prices should initially fall due to increased supply from the slaughter and marketing of exposed (not infected) animals, and should rise as herds are rebuilt after the lifting of the quarantine. On the other hand, it is not known how consumers will react to a FMD outbreak, even though it is known not to affect humans.

In summary, it is assumed that the indirect and induced impacts on other sectors of the economy are more important than the price effects in the livestock and dairy sectors.

The basis of an I/O model is a matrix that describes commodity flows through the economy, moving from producers to intermediate and final consumers. This matrix is a descriptive framework for showing the relationship between industries and sectors, and between inputs and outputs. Figure C1 represents a basic I/O transaction (or gross flows) matrix.

Figure C1

From	To	Purchasing sectors			Local final demand			Exports	Total gross output		
		1	...	j	...	n	Households			Private investment	Government
\forall	>										
Producing sectors	1	X_{11}	...	X_{1j}	...	X_{1n}	C_1	I_1	G_1	E_1	X_1

	i	X_{i1}	...	X_{ij}	...	X_{in}	C_i	I_i	G_i	E_i	X_i

	n	X_{n1}	...	X_{nj}	...	X_{nn}	C_n	I_n	G_n	E_n	X_n
Labor		L_1	...	L_j	...	L_n	L_C	L_I	L_G	L_E	L
Other value added		V_1	...	V_j	...	V_n	V_C	V_I	V_G	V_E	V
Imports		M_1	...	M_j	...	M_n	M_C	M_I	M_G	--	M
Total gross outlay		X_1	...	X_j	...	X_n	C	I	G	E	X

Row i in the table shows the sales of industry i to all other industries (intermediate demand) and to consumption, private investment, government spending and exports (which are the components of final demand). Intermediate demand plus final demand measures total gross output (or sales) of industry i . Conversely, column j shows the purchases of industry j from all other industries (intermediate inputs), from primary inputs (labor, capital, etc.) which are value added entries taking the form of wages, profit, rent, interest and taxes, and from imports.

By making certain assumptions about the economic system, and in particular about the sectoral production functions, the I/O accounts of Figure C1 can be transformed into an analytical model (Richardson, 1972). For simplicity of exposition, assume that there are only three sectors, that there is only one final demand (Y) and only one source of value added (V). Summing across each row and rearranging, results in

$$X_i - X_{i1} - X_{i2} - X_{i3} = Y_i \quad (1)$$

If the amount of industry 1's output purchased by each of the purchasing industries is a stable function of the latter's output, equation (1) may be written

$$X_i - a_{i1} X_1 - a_{i2} X_2 - a_{i3} X_3 = Y_i \quad \text{for all } i \quad (2)$$

where

$$a_{ij} = \text{write equation!!!}$$

The a 's are called *direct input coefficients*, and in a n sector model they represent the direct requirements of the output of any sector i per unit of output of any other purchasing sector j . The crucial assumptions for equation (2) to hold are: (1) there are no joint products, since each commodity is supplied by a single industry and via one method of production, (2) all production functions are linear, implying constant returns to scale and no substitution between inputs, (3) additivity, i.e., the total effect of production is the sum of the separate effects, which rules out external economies and diseconomies, (4) the system is in equilibrium at given prices, and, (5) in static versions of the I/O model, there are no capacity constraints, so that the supply of each good is perfectly elastic.

As was pointed out before, the total effect of an external shock to the production system can be separated into direct and indirect effects. To estimate all direct and indirect effects it is useful to express the system in matrix notation. Equation (2) becomes now

$$X - AX = Y \quad (3)$$

where X and Y are column vectors of gross output and final demand respectively, and A is an $n \times n$ matrix of direct input coefficients, a_{ij} . Equation (3) may be rewritten as

$$(I - A)X = Y$$

where I is the identity matrix. Under the condition that $(I - A)$ has an inverse (in practical terms, this condition is met if the Y vector contains at least one non-zero element), gross output can be ex-

pressed as a function of final demand

$$X = (I-A)^{-1} Y = B Y$$

The matrix B is called the Leontief inverse. Its elements are called the interdependency coefficients and represent the direct and indirect requirements of sector i per unit of final demand for the output of sector j .

Repercussion of exogenous changes on total income and employment can be estimated via the concept of the multiplier. The income multiplier (as originally developed by Keynes) indicated the total growth in income induced by an autonomous shift in demand, once all direct and indirect effects were accounted for. I/O models allow estimation of different types of multipliers depending on whether the interest is in output, income or employment.

Output multiplier

The output multiplier for industry i simply measures the sum of direct and indirect requirements from all sectors needed to deliver one additional dollar of output of i to final demand. It is derived by summing the entries in the column under the industry i in the Leontief inverse matrix table.

Income multiplier (type I)

It is defined as the ratio of the direct plus the indirect income change to the direct income change resulting from a unit increase in the final demand for any given sector.

Income multiplier (type II)

It is defined as the ratio of the direct, indirect and induced income change to the direct income change resulting from a unit increase in final demand. The basic assumption used in the calculation of this multiplier is that the relationship between changes in final demand and changes in household expenditure is linear. Because of this linear relationship, the economic impact is overestimated.

Income multiplier (type III)

The type III multiplier compares direct, indirect and induced effects to the direct effects generated by a change in final demand. To minimize the overestimation caused by the linear consumption function used in the type II multiplier, the induced effects are based on the changes in employment and population.

In spite of their limitations, I/O models have been widely used for economic research and planning. Thorough reviews of this technique can be found in Miller and Blair (1985) and Richardson (1972).

APPENDIX D
LIST OF CONTACTS

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APPENDIX E

RECENT FMD OUTBREAKS IN TAIWAN AND ITALY

The contagious nature of the FMD virus and the difficulties of dealing with an outbreak can be appreciated through analysis of recent experiences in Taiwan (Shieh, 1997) and Italy (Maragon et al., 1994).

The first case in Taiwan was reported on a farm located in the northwest section of the island on March 14, 1997. By the end of March, 1,300 farms scattered over most of the country were affected. An affected area covering all prefectures and cities in the western part of the main island was declared on March 21. The Central Mountain Range, which runs lengthwise through the main island, provided a natural barrier to the outbreak and initially the disease did not spread to the eastern part of Taiwan; other off-shore islands also were not infected at that time. At the beginning of May, the infected area was extended to cover the whole main island. As the disease spread so widely, nationwide vaccination of all cloven hoofed farm animals, in addition to the depopulation of infected herds, was decided upon.

The Army helped in carcass disposal, including burying, rendering, and incineration or burning. Burying was the most commonly used technique. The choice of the disposal method depended on the location of the infected farms. Farmers were allowed to send their pig carcasses to nearby rendering plants under the supervision of a veterinarian. In water resource protection areas, only incineration using movable incinerators or open field burnings was adopted. At the peak of the eradication campaign, a disposal capacity of 200,000 pigs per day was reached. By June 4, 6,143 farms had been affected. The number of exposed susceptible animals reached 4.66 million head, the number of cases was 1 million and 3.85 million animals were slaughtered (Shieh, 1997).

All FMD-susceptible animals on the eastern side of the island, as well as the dairy cattle and the more valuable breeding pig herds elsewhere, were vaccinated. The first round of vaccination with a polyvalent vaccine was completed by the end of March. Other vaccination rounds with vaccines containing only one strain followed. By May 3 a total of 13 million doses of vaccine were supplied by the government to farmers free of charge.

The vaccination did not slow the spread of the disease in the eastern region of the island, and the proportion of infected animals in the total susceptible population in the eastern provinces did not show any significant difference from provinces in the rest of the island. There was a strong association between the proportion of infected animals in the susceptible population and the number of animals in the region, suggesting that animal density was a major factor in the spread of the epidemic.

The origin of the epidemic is suspected to be smuggled food products introduced through a port about 10 km away from the farm where the first case was reported. The farm was family operated with good management practices. Even though no animals nor other personnel were introduced into the farm during the month prior to the outbreak, large flocks of sparrows flew in and out (Shieh, 1997). After repopulation of previously infected premises was allowed on December 1997, Taiwan suffered new outbreaks of FMD.

FMD was introduced into Southern Italy in 1993 by infected cattle imported from Eastern Europe. By the time FMD was confirmed, the cattle had been distributed to a number of premises both in Northern and Southern Italy (Maragon et al., 1994). The infection spread despite prompt identification and elimination of the infected herds, the absence of animal movements and atmospheric conditions favorable to the eradication efforts. This outbreak was the first in Europe after the cessation of vaccination in 1991.

On March 11 a premise in southern Italy was identified as infected. On the same day, the Veterinary Division of the Ministry of Health informed the health authorities in the Veneto region that a truck laden with beef cattle had left the infected premises on March 3, and had unloaded at a beef fattening facility on March 4. The infection was confirmed there on the same day. At the time of the inspection 93 cattle had lesions and the whole herd of 445 cattle was slaughtered the next day. In the next two weeks another three outbreaks were identified in a limited area close the first outbreak. The second outbreak was identified on March 15 and 376 head of cattle were slaughtered the next day. The only direct contact that could be traced between the two outbreaks was a sugar beet pulp lorry that visited both farms on March 10, the day before the first outbreak was detected. A third outbreak was confirmed on March 22 in a large beef unit. No direct or indirect contacts with the first and second outbreaks could be identified, but the premises were only three km away from the first outbreak and one km from the second.

The fourth outbreak was detected on March 27 in a feedlot located about four km from the second outbreak. The only direct contact that could be traced between those two premises was a feed technician who had visited both on March 11. Two large pig farms, containing altogether about 2,500 pigs, located at a distance of less than one km from the fourth outbreak were depopulated as dangerous contacts.

Investigations revealed that there were no movements of livestock in or out of the infected premises. The only other movements involving a risk of spreading the FMD virus that could be identified were the sugar beet truck and the feed technician. However, all four outbreaks were adjacent to a main road. The European guidelines to deal with a FMD outbreak include the creation of protection and surveillance zones; these normally have radii of three km and 10 km respectively. After the fourth outbreak a protection zone of five km was instituted.

The following measures were applied in the protection zone (Maragon et al., 1994):

- A daily clinical examination of all susceptible herds. Each veterinarian visited a small number of farms each day. Pig units, which posed a far greater risk, were visited by a veterinarian who did not approach any other livestock units.
- Virological examination of bulk milk from all dairy farms in the area in an attempt to detect incubating infections.
- All milk produced in the surveillance and protection areas was collected separately and delivered to a processing plant which produced milk only for human consumption. The milk was treated by ultra high temperature (UHT) to render it safe.
- A whey factory which produced whey to feed 1,800 fattening pigs was closed.
- All agricultural activities such as artificial insemination (AI), mastitis control, milk yield recording, etc. which could involve a risk of indirect transmission of the virus were canceled.
- Several fixed points were organized for the disinfection of feedstuff lorries and other vehicles, and all vehicles visiting farms had to be disinfected before and after each visit.
- Police check points were instituted to avoid uncontrolled movements of animals and vehicles.
- The main highway crossing the surveillance zone was closed to lorries carrying cloven-hoofed animals.

A computer analysis of meteorological data suggested that the airborne spread of infectious particles had been limited by prevailing anticyclonic conditions. Surveillance was therefore concentrated on the 132 livestock units within the protection zone and the infection was prevented from spreading. There were 897 units within the surveillance zone. Because of such a large number of premises, it was beyond the resources of the veterinary services to inspect each of them daily and the authorities had to rely on the stock owners in the surveillance zone to report possible cases of FMD. It was estimated that a veterinarian could inspect a maximum of eight to ten herds each day.

APPENDIX F

LITERATURE REVIEW

The literature on epidemiology of highly infectious diseases can be divided into four large groups: spatial epidemiologic models and management systems, non-spatial epidemiologic models, economic analysis of control and eradication strategies, and papers covering a variety of related topics.

Spatial epidemiological models

Spatial epidemiological models generally use a GIS to forecast the diffusion of outbreaks of infectious diseases. Moutou and Durand (1994) analyze airborne diffusion of FMD with a predictive model that links epidemiological data associated to viral particle excretion and meteorological data related to the few days before the slaughter of animals. The model computes the expected quantity of viral particles that could be found in a 10 km radius around the outbreak in every space direction, and that originated on the breath of a sensitive animal. The model is used to define a risk area, according to the number and size of farms in the surroundings.

Casal et al. (1997) simulated atmospheric dispersion of virus using a model that has been developed for predicting the dispersion of toxic gases from chemical engineering plants. The results were compared with data from two outbreaks of Aujeszky's disease and two of FMD in which virus was believed to have been transported by air. The model provides estimates of the mean dose of virus received by an animal at a farm downwind.

The New Zealand Ministry of Agriculture and Fisheries developed a decision system for managing a FMD epidemic (Sanson et al., 1991). The system, known as EpiMAN, comprises a database management system, a geographic information system, a spatial simulation model of FMD and a number of expert systems. A number of studies were conducted to gather the data required by the system.

- Sanson and Morris (1994) used survival analysis linked to a GIS to estimate the probability of a farm contracting FMD due to local and windborne spread, where the independent factor is distance from a source infected farm. Historical data from the FMD epidemic of 1967-1968 in the UK were used to estimate diffusion probabilities, with the data set restricted to those farms in which the most likely reason for infection was recorded as local or windborne spread. Their findings show that the probability of FMD infection in the period covering one day prior to the appearance of clinical signs to 2 days after the signs appeared was 0.13 for farms within a 3 km radius from the source and 0.015 for farms within 3 and 5 km from the source.
- A survey of Southland farms in New Zealand was conducted to assess the potential for FMD dissemination through normal movement patterns of farm animals and materials over a period similar to

what would be expected from the time the virus arrived on a property to the time of diagnosis (Sanson et al., 1993). Each farmer participating in the survey was required to complete a diary, recording all movements of people, animals and materials onto or off the farm during a 14-day period. The mean number of movements recorded per farm was 50. The majority of movements occurred within the immediate neighborhood of the origin, with 31.5% and 56.5% of all movements occurring within 5 km and 10 km respectively. A radius of 100 km would contain 95% of all movements. The mean number of high risk movements that occurred over the 100 km radius was 3.4.

The EpiMAN system is now being adopted by the EU, and consists of a central database for farm information, a GIS for spatial data, epidemiological and economic simulation models, and expert systems containing factual knowledge about FMD (Nielen et al., 1996a). The aim of the system is to support decision makers in both the operational and tactical management during a FMD outbreak, but the system may also be used as a training tool. The system allows to list all farms in a determined area, and also predicts the size and movement of the virus plume. The main difference between the European and the New Zealand versions of EpiMAN is that the former includes an economic model to evaluate alternative control and eradication policies.

Studies in several European countries have been conducted to calibrate the system to the different conditions prevailing in different regions. Among these studies, a survey of Dutch farms was conducted to quantify contacts among farms (Nielen et al., 1996b). Farmers were asked to report all movements in and out of their farms during a two week period. These records were compared with regularly scheduled visits, such as AI technicians and veterinarians. A major result of the study was discovering the difficulty of farmers to accurately report all movements, even in a controlled experiment. This finding has major implications for FMD control. In case of an outbreak, producers are asked to remember all animal movements in and out of the farm in the previous 21 days and all other contacts in the previous 15 days. Exact identification of the days in which the movements occurred is also required to relate them to the date in which the outbreak was identified in the farm. This may prove to be very difficult, judging by the high number of contacts recorded by both the New Zealand and the European studies.

The European studies found that the average number of contacts per farm (91) was almost twice the number in New Zealand (50). This is likely due to differences in the livestock industries, and the smaller distances between farms in the Netherlands. Regression analysis showed that in both cases neither the pattern of movements nor the distance between farms or riskiness of the contacts are affected by farm characteristics. In other words, in case of an outbreak all farms should be treated as having equal risk of becoming infected. The relative size of the farm remains possibly the most important indicator at the start of an outbreak, when no other information is available; this is particularly relevant for airborne diffusion of the outbreak.

A similar but less developed information management system was used to analyze the spread of pseudorabies in Minnesota swine herds (Marsh et al., 1991).

Hungeford (1991) used a GIS to analyze three issues relevant to epidemiology: whether a disease is clustered, whether two diseases, or a disease and potential risk factors have the same distribution, and if there are specific definable relationships between the values of the same variable at different locations. Join count statistics (which relate actual and expected number of joins between areas with dissimilar values) and second order analysis (which compares the actual and expected distances between all points weighted by their values) give estimates of the magnitude and statistical significance of clustering in patterns.

Kitron et al. (1991) studied the association of tick distributions with soil type, potential vegetation cover and distance from waterways, and compared the dispersion patterns of tick-infested and uninfested deer in one northwestern Illinois county with the help of a GIS.

Non-spatial epidemiological models

Non-spatial epidemiological models generally use a Markov chain or a state-transition model to analyze the spread of an outbreak of an infectious disease.¹⁴ Markov chains are used to analyze the changes over time of systems that can be defined in terms of a number of possible outcomes or states that can occur. A Markov chain has two components: states and transition probabilities. States are defined as the possible groups (or situations) in which an individual can be at any particular moment. The transition probabilities represent the probability that an individual will move to state j in the next period when presently it is in state i . There are many types of Markov chains. First-order Markov chains are the ones most used in epidemiological studies. They have the following characteristics:

1. States and transitions are discrete (e.g., one per week).
2. The number of states is finite.
3. Transitions depend only on the current state, not on prior states. In other words, the whole history of the process is contained in the current state. To simplify the presentation, the transitions are usually presented in matrix notation; the matrix is known as the transition matrix.
4. Transition probabilities remain constant over time.

Markov chains are used to estimate the expected state of a system after a certain period of time (which may be infinite). By attaching payoffs to each state, it is possible to estimate the expected value of alternative policies (Taylor and Karlin, 1994). Markov models are more appropriate to model diseases which are more endemic (or static) than those based on the Reed-Frost equation which are better suited to model highly contagious diseases. Even though Markov models have been extensively used in both human and animal epidemiological studies, they will not be reviewed due to their limited use to model a FMD outbreak; references can be found in Carpenter (1988b).

¹⁴ A more comprehensive view of simulation models applied to epidemiology can be found in Hurd and Kaneene, 1993

State transition models have a mathematical structure similar to a Markov chain, but one or more transition probabilities are not constant, and are defined as a function of the state of the system in the previous period of time. The basic assumptions of these types of models are that the period of infectiousness is constant, relatively short, and there is a constant probability of infection in each period of time. The most used model in this category is the Reed-Frost model, where the expected number of cases of the epidemic can be derived deterministically from the recursive formula:

$$C_{t+1} = S(1 - q^{C_t})$$

where C is the number of cases at time t , S is the number of susceptible individuals, $q = 1 - p$, and p is the probability of effective contact.

Carpenter (1988b) contains two epidemiological models, one modelled as a Markov process and the other as a state transition model. The Markov model evaluated multi-agent mastitis transmission and control alternatives in a dairy herd. The model assumed six states according to infection status, allowed for culling and restocking, and had constant transition probabilities. The second model was a modified version of the previous model. Culling and restocking were not allowed and the transition matrix was modified assuming that the number of animals infected with *Streptococcus agalactiae* at any time was dependent upon the number of animals infected with *Streptococcus agalactiae* during the previous period and the probability of avoiding effective contact in the Reed-Frost equation.

Carpenter (1988a) presents an epidemiological model based on the Reed-Frost model in which: i) the exposed population is vaccinated, ii) vaccine immunity wanes and is random, and iii) the number of effective contacts varies randomly among periods.

Using a state-transition model, de Jong and Diekmann (1992) derived an analytic expression for the basic reproduction ratio of the infection, i.e., the number of cases caused by one typical infectious animal. When this ratio is larger than 1, the infection can spread; when the ratio is smaller than 1 the infection will disappear. Therefore, a strategy for controlling an infective agent is effective only if it drives the ratio below one. The structure of the formula allows investigation of the influence of certain parameters (e.g., infection, demographic or control-strategy parameters) on the spread of an outbreak.

Garner (1992) describes a likely FMD outbreak based on various assumptions of how the disease may behave under Australian conditions; the effect of various factors on the course of an epidemic, and assessment of potential requirements of a vaccination strategy should this be considered are also examined. The model, a stochastic state-transition model, enables quantification of the effects of key variables of a FMD epidemic, including the effective contact rate that will apply, the delay between disease introduction and application of control measures, and the types and effectiveness of specific outbreak scenarios.

Cleland et al. (1994) analyzed immunity to FMD in Thai cattle and buffalo herds with a state transition model with two states (susceptible and immune); the main parameters were deaths, culling,

births and vaccination rates. A proportion of vaccinated animals lost immunity in the months separating vaccinations. The model was calibrated with data collected from 60 Thai villages. The main result is that to be effective, vaccination has to cover almost 100% of susceptible animals.

Other state transition models used to estimate the economic impact of FMD have been published; these are reviewed in the next section.

Hurd et al. (1993) present a stochastic distributed-delay model that can be used to represent both infectious and non-infectious diseases, and compares its behavior to a stochastic version of the Reed-Frost model for a hypothetical infectious disease. Both models produced similar results in terms of the average attack rates, and the bimodal distributions of total number of cases per epidemic. The shape of the distributions, though, was slightly different. Separation between the two peaks was not as great with the distributed delay model as with the Reed-Frost model. The tail was slightly more extended than the Reed-Frost, and there were more epidemics in the 50-100 case range.

Mortensen et al. (1994) used a meteorological dispersion model to analyze two outbreaks of Aujeszky's disease in Danish hog farms in regions known to be free from the disease. Their findings show that location, weather patterns and herd size are all statistically significant predictors of the hazard of infection. Herd size was also found to be positively correlated with the risk of infection by Willeberg et al. (1994). The factors mentioned as responsible for this size effect are:

- Direct effects of the number of animals on disease introduction,
- Spread and maintenance of infections within the herds,
- Different management in large and small herds,
- Misclassification of herd status when testing many animals.

The concentration of virus in the air is not homogeneous, and the amount of virus inhaled by animals can follow a Poisson distribution (Casal et al., 1997). As a result, even with low mean doses, some individual animals could have received a large enough dose to be infected. Under these assumptions, larger farms would have a higher probability of one animal receiving a dose large enough to become infected than smaller farms.

Models used to estimate the cost of a FMD outbreak

The value of the losses caused by a FMD outbreak has four components: (1) the direct cost of dealing with the outbreak (cleaning and disinfection, compensation to producers, quarantine enforcement, etc.), (2) production losses, (3) induced price changes, and (4) the effect on other sectors of the economy. Different ways to estimate the value of losses have resulted in four methodologies: accounting methods, cost-benefit analysis, welfare analysis, and input-output (I/O) models.

Calculation of the first component is straightforward accounting. Estimation of the second component is usually done with an epidemiological model that estimates the physical production losses which are then converted to monetary values.

If the production losses are substantial or markets are disrupted by the outbreak, then both supply and demand of beef are affected resulting in a change in prices. In addition to domestic price changes, trade restrictions can reduce the price received for exports of animals and animal products. If prices rise, consumers will lose because they will have to pay more for their beef, while the loss to producers will fall because they will receive a higher price for their reduced output. The full value of price changes can be estimated with welfare analysis.

All production establishments purchase inputs and sell outputs from other economic agents (suppliers, workers, etc.). These agents, in turn, buy and sell products inducing additional economic activities that spread to the rest of the economy. Through these direct, indirect and induced linkages, a FMD outbreak not only affects the infected premises but the whole economy. Input-output (I/O) analysis estimates the direct and indirect cost of the outbreak to the whole economy.

The main limitation of welfare analysis is that it only considers price changes in a single market and does not include effects on other sectors of the economy. The main limitation of I/O analysis is that it does not include price effects. A problem shared by both methodologies is that they require large amounts of data. The selection of the methodology to be used should be based on the assessment of the relative importance of both effects, and on data availability.

Dufour and Moutou (1994) is an example of the accounting methodology. They estimated the direct costs of two alternative control strategies (i.e., annual vaccination and stamping-out) in France under the assumptions that i) both strategies are equally efficient in containing an outbreak and ii) the production losses incurred with both strategies would be equal. The direct cost of stamping-out is about 9% of the cost of annual vaccination. While the first strategy relies on the individual efforts by farmers (even though with a strong control by government veterinarians), the second strategy relies heavily on education, information and prevention by all parties involved in the livestock industry. Because of this shift in emphasis, the share of total costs borne by the state and local communities increases from 20% to 56% of the total costs.

Cost-benefit analysis considers not only the direct cost of an outbreak but also production losses over time. In some cases, it may include some losses to suppliers and customers of the affected sector and discrete changes in prices. The costs are the direct costs of the eradication campaign while the benefits are the losses avoided by using a particular control strategy. Both costs and benefits are calculated for a number of years and discounted to the present. This methodology is the easiest way to evaluate alternative control and eradication strategies. Its main drawbacks are that it does not consider the full price effects nor all the direct and indirect linkages.

Ellis (1994) details the basic procedures of cost benefit analysis and their application to evaluate FMD control strategies from the nation's and farmers' points of view. Van Ham (1994) estimated the damage to the Israeli dairy herd caused by FMD outbreaks and conducted a cost/benefit analysis of the present vaccination policy. The patterns of spread, the political situation at the borders, and the fact that the neighboring countries do not take adequate steps to eradicate the disease cause a FMD episode nearly yearly (64% of the last 22 years). The vaccination policy and other precautions keep the losses in Israel on a stationary level. A cost/benefit ratio of 46.5 was calculated by comparing the vaccination policy with the alternative of stamping-out without vaccination.

Andersson et al. (1997) use welfare analysis to analyze the social benefits of an eradication program of Aujeszky's disease in Sweden under three different policy regimes: government price support, internal market deregulation and EU-membership. The policy setting determines the magnitude and distribution of both benefits and costs. The total benefits of the program are evaluated across herd and size categories and different regions, consumers and the government.

Studies based on the welfare analysis have been widely used to analyze a large number of diseases. McCauley et al. (1979) estimated the economic costs of a FMD outbreak in the U.S. over a period of 15 years with several control strategies. One of the possible outcomes contemplated was FMD becoming endemic and vaccination used to reduce production losses. The outbreak was simulated with a state-transition model, that included four states (susceptible, infectious, immune and removed) and four strategies: (1) the current preventive policy of restricting imports of animals and animal products, (2) a stamp-out policy, (3) an area vaccination program aimed at achieving eradication, and (4) an endemic situation with two alternatives, compulsory vaccination program (under government control) and voluntary vaccination. The economic losses were estimated with an econometric model of the U.S. livestock industry. The model calculates the losses borne by consumers due to the reduced supply caused either by production losses or depopulation under the stamping-out policy. The main conclusions of the study are:

- If FMD is introduced into the U.S. and becomes endemic with only voluntary control (the benchmark policy), the discounted present value of losses over a 15 year period is estimated to be almost \$12 billion (at 1979 prices).
- The policy of restricting imports of animals and animal products has a benefit-cost ratio of 120 to 1 with respect to the benchmark.
- The stamping-out policy would be within limits of economic feasibility even if 1% of the national herd was slaughtered in the eradication effort. Such a massive eradication effort yields a benefit-cost ratio of 19.7 to 1.

Berentsen et al. (1990 and 1992b) developed an integrated approach to determine the economic consequences of alternative strategies to prevent and control FMD in the Netherlands. The approach

is based on a state-transition epidemiological model that determines the diffusion of FMD in Dutch herds under different preventive and control strategies, and an economic model that evaluates the social cost of each strategy. The model calculates separately the changes in consumer and producer surplus, and the budgetary cost to the government; particular attention is given to the consequences of FMD on beef exports. Separate calculations were made for three regions with different production conditions. Patrick and Vere (1994) apply a similar methodology to estimate the ex-ante benefits of an eradication campaign of Haemorrhagic Septicemia in Indonesia.

Dijkhuizen, Hardaker and Huirne (1994) evaluate several decision rules to show the impact of various risk attitudes of decision makers in determining what FMD control strategy to choose. Berentsen et al. (1992a) discuss the principles of cost-benefit analysis, stemming from neo-classical economic theory and welfare economics, and apply these principles to the analysis of an epidemic of a foreign disease in a beef exporting country. They analyze critically published cost-benefit analysis of FMD stressing the importance of producer and consumer surplus analysis.

Buhr et al. (1993) advocate the use of consumer and producer surplus to measure the total cost caused by an animal disease. The paper presents an econometric model containing lagged variables to estimate the supply and demand curves. Models that include lagged variables are reduced form specifications of structural dynamic models. The main problem of the proposed methodology is that consumer and producer surplus are well defined for static functions, but they have not been defined for dynamic specifications. An additional concern about this methodology when applied to FMD is that welfare measures are valid for marginal displacements of the supply and demand schedules. The cost of a FMD outbreak in a non-infected country, however, is likely to be very large.

Garner and Lack (1995) is an example of input-output analysis. They evaluate four control options (stamping-out, dangerous contacts slaughter, and early or late ring vaccination) for FMD in three different regions of Australia. A stochastic disease simulation model was used to generate outbreak scenarios, and an I/O model converted outbreak effects on farming and processing operations and subsequent effects of control programs into estimates of total economic impacts. The results show considerable regional variation according to ecological and productive conditions.

Krystynak and Charleboys (1987) does not belong to any of the four categories mentioned above. They used Agriculture Canada's Food and Agriculture Regional Model (FARM) to estimate the economic impact of trade embargoes that would follow a FMD outbreak in Canada. The FARM model is a large scale, multiple equation econometric model representing the economic relationships describing the Canadian agri-food system. Two scenarios, a small and a large outbreak, were simulated over a five year period; the epidemiology of the disease was not modelled and losses arise exclusively from trade disruptions caused by import bans imposed by importing countries. The results indicate that even a small FMD outbreak would have serious economic consequences for the livestock sector with farm cash receipts declining by \$2 billion (1987) Canadian dollars.

Other topics related to FMD

Forbes et al. (1994) report the results of a workshop conducted in New Zealand to analyze the risk of introduction of FMD and assess the contingency plans to deal with an outbreak. The main concern of the participants was the lack of public awareness of the risks of the introduction of FMD by passengers arriving in New Zealand. Other factors mentioned were the tendency for commercial pressures to override technical standards, constraints in monitoring and surveillance services, the government's cost-recovery directives and weaknesses in the response program. Smuggled meat products were perceived to pose the greatest risk for the entry of FMD virus to New Zealand in the medium term, while a terrorist attack or criminal intent was perceived to pose the highest risk in the long term. The largest risk was perceived as coming from Asian-Pacific countries. The risk of a FMD outbreak was assessed as 1 chance in 50 years. As was the case with other countries, funding (both in levels as well as its variability) was one of the major concerns of the participants and was indicated as the most important factor affecting the effectiveness of the response to an outbreak.

A similar study is reported in Horst et al. (1996) for the EU. The relative importance of six risk factors concerning contagious animal diseases was estimated with conjoint analysis based on the opinion of expert respondents. FMD was one of the diseases included in the study and the risk factors considered were: imports of livestock, imports of animal products, feeding of swill, tourists, returning livestock trucks and airborne diffusion. Imports of livestock was ranked by respondents as being the largest risk of introduction of FMD, followed by imports of livestock products. The difference in the perceived relative importance of both risk factors was 43%. Garbage fed pigs were deemed as the third largest risk.

Donaldson and Doel (1994) analyze the new risks posed to the United Kingdom by the sanitary guidelines introduced by the EU in 1992 in the transition to an unified market. The elimination of FMD, the interruption of preventive vaccination in all member states and the adoption of a unified sanitary policy allow for increased trade opportunities. On the other hand, suspension of the vaccination will increase the risk of virus introductions. The main entry vectors to the UK would be live animals in which the disease is mild or asymptomatic (in particular, sheep and goats), and airborne diffusion originating in pig farms in Bretagne and areas of Benelux with high animal densities.

Maragon et al. (1994) report on the epidemiological investigation of the 1993 FMD epidemic in northern Italy. The livestock units are large (for European standards) and the cattle are permanently housed in covered yards. The Italian epidemic was the first to occur in the EU since the cessation of mass vaccination in 1991. The outbreak started in southern Italy; the source of the infection appears to be consignments of cattle imported from Eastern Europe and spread north through a lorry with infected cattle. As soon as FMD was confirmed in southern Italy, all movements of animals were traced and sanitary authorities in the north were alerted. Eradication of the outbreak was simplified by favorable atmospheric conditions, reduced contacts between herds and early detection. The area

at risk was delimited by the meteorological conditions using the model described in Moutou and Durand (1994) and the contacts between outbreaks. Delimitation of the high risk area with the meteorological model allowed to concentrate efforts in those areas where the infection risk was higher. In this epidemic, dangerous contact herds were slaughtered because they presented an unacceptable risk, particularly in the case of pig units.

Donaldson and Kihm (1996) reviewed recent advances in tests for the diagnosis of FMD, in addition to advances in surveillance, vaccinology and information technology, i.e., computing and networking. The first line of defense against FMD is the control of animal movements, especially imports. The tests used for screening animals must have a high degree of sensitivity and specificity to ensure that trade is not impeded but also to ensure that the indigenous population is protected. Tests can be for direct FMD virus or indirect serological tests. Recent advances in indirect tests have been in the direction of developing analyses based on monoclonal antibodies directed against a non-structural protein of the virus; such procedure would be serotype independent, thereby eliminating the need to test for antibodies against a range of serotypes. New progress in direct tests has been made in the development of immortalized bovine thyroid cells and this could be the basis of alternative direct tests for FMD. Another approach would be to test nasal swabs for the presence of viral RNA by the PCR method. Promising advances have also been made in detecting FMD antibodies in milk. Rapid recognition of a suspected case and speedy implementation of control measures are essential for the rapid eradication of the disease. The first contact with the disease will be by farmers and field veterinarians so it is essential that they are aware of the key features of the disease. Members of the National Veterinary Service should be trained in the contingency plans. A contingency plan should be created to secure full and speedy compensation to farmers when a stamping-out policy is applied. The use of modern computer based systems for management of FMD epidemics can greatly improve the efficiency of control and eradication strategies.

Lorenz (1986 and 1988) analyzed a number of FMD epidemics in non-protected populations of cattle and pigs in Europe between 1965 and 1982, and reported a highly skewed distribution of epidemic size with a range of 1 to 6,400 infected properties, a median of about 30 and a mean of 1,050. The majority of epidemics in unvaccinated populations involved less than 35 secondary properties, but occasionally a large epidemic was caused by a combination of factors favorable to the rapid and widespread dissemination of the virus through the animal population.

Saatkamp et al. (1994) and Saatkamp et al. (1997) report the results of an economic evaluation of four different identification and recording systems combined with two control strategies in contagious disease control in Belgium. The identification and recording methods analyzed are: 1) eartag identification and manual recording with documents; 2) eartag identification and manual recording with computerized data storage; 3) electronic identification using transponders and electronic data transfer and computerized data storage; and 4) as the previous system but with bio-sensors allowing

physiological monitoring of animals. The lowest control cost is achieved with the fourth system; the paper does not test, however, whether the system is economically viable given the greater cost of the transponders. The most important result, though, is the large reduction in the cost of an outbreak obtained when strategy 1 is replaced by strategy 2.

Callis (1996) reviews the risk posed by different traded commodities. Even though FMD virus has been found in bull semen, no outbreaks have been traced to exposure to infected semen even among animals that were never exposed to the virus. Many species can become carriers following infection, nonetheless the spread of FMD from carriers to susceptible animals has not been demonstrated. It is not recommended, though, that carriers be mixed with susceptible animals. Embryos from cattle, sheep and goats, when they have intact zona pellucida and when washed according to IETS recommendations, may be safely transferred from FMD-infected and recovered cattle without transmitting the infection. The FMD virus is inactivated in muscle within 24 to 72 hours after slaughter if the carcass is kept above freezing temperature, due to the reduced pH. In contrast, the virus may survive for weeks or months in refrigerated internal organs, bone marrow, lymph and haemal nodes, glands and residual blood. During infections large quantities of FMD virus may be found in milk some time before the development of clinical signs. Virus in milk disappears with the development of neutralizing antibodies. FMD virus in milk may survive both short and long pasteurization; either method reduces the titre of FMD virus significantly. Ultra-high temperature processing is sufficient to inactivate the virus. The virus survives the processing of casein or caseinates. FMD virus survives the processing of certain cheeses. However, the infectivity remaining after processing disappears with aging or ripening.

