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The Distributional Impacts of Technical Change
on the U.S. Dairy Sector

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Abstract

The regional impacts of technical change on the U.S. dairy are assessed in terms of production and income distribution through a dynamic equilibrium model. Productivity increases are projected to raise the national market share of the Northeast, Lake States and Pacific regions at the expense of the remaining seven regions.

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Introduction

As debate begins on the new Farm Bill, one of the continuing areas of interest to legislators is the future structure of American agriculture. Advancements in biotechnology and information technology are likely to accelerate the treadmill process and adjustment problems which have effected agriculture in the past. The most dramatic impacts may be felt first in the dairy sector where growth hormones are soon to be commercially approved. Given the productivity gains to be achieved and the associated adjustment problems to be suffered, a need exists for an ex ante assessment of the distributional impacts of new technologies. The OTA study provided an initial analysis on the projected relationship between biotechnology and farm structure. However, its use of accounting costs to determine regional advantage has been criticized (Jesse and Cropp, Stanton). Despite the criticism, recent studies such as Fallert et. al. have also relied on the construction of typical farms based on cost data to project future effects of biotechnology.

The purpose of this paper is to assess the regional impacts of technical change on the U.S. dairy sector in terms of both production and income distribution. As an alternative to the previous studies which have relied on static economic cost figures, a dynamic partial equilibrium model of the U.S. dairy sector is constructed to account for production characteristics and adjustment responses of each region within the context of the prevailing government support program. The model is simulated under alternative rates of technical change and the generated equilibrium prices and quantities are used to calculate regional production and income levels over time.

The Dynamic Model of the U.S. Dairy Sector

The complete model is illustrated in Figure 1. Milk production (Y) is determined at the regional level through the choice of a variable input feed (X) and two quasi-fixed inputs, cows (C) and labor (L). The three inputs are chosen based on data availability.

Milk production, feed use, and cow numbers are provided by state and labor use by region. Although additional data may exist for particular states or for the whole farm sector in each state, construction of further milk production inputs from these sources would involve arbitrary assumptions.

The regional producer core equations for each of these variables is derived by solving a dynamic optimization problem in which the firm is assumed to maximize profits over time net of internal adjustment costs. Rather than explicitly solving this model, a theoretically consistent system of equations are derived by utilizing the duality relationship established by Epstien between the production function and the optimal value function which represents the maximum present value of rents accruing to the quasi-fixed inputs. The linkage is the Hamilton-Jacobi equation. The milk supply and input demand equations are derived through application of the intertemporal analogue of Hotelling's lemma to this equation. The first step in this process is the specification of a functional form for the value function on which the Hamilton-Jacobi equation is based. Given the results of Howard and Shumway (1987), a modified generalized leontief is chosen.

Other studies which have utilized dynamic duality theory to model the producer core equations include Vasavada and Chambers, Howard and Shumway (1988), and Vasavada and Ball. However, these works have not simultaneously estimated the input supply equations necessary in order to derive equilibrium prices and quantities. These input supply equations are determined here through static optimization procedures. The produced inputs of feed concentrate and milk cows are assumed to be derived from profit maximizing behaviour on the part of the supply firms. Thus, the supply of feed and cows will be a function of own price, the price of an alternative commodity, and an input price. In contrast, labor is a primary input possessed by consumers and the amount sold to producers will depend upon the wage rate within and outside the sector (R_L and R_{LNA}), the size of the civilian labor force (CLF), and general economic conditions as measured by the unemployment rate (UE). A time trend variable (T) is included in all input supply equations to account for structural shifts or changes in preferences. The effect of capacity constraint and sluggish adjustment

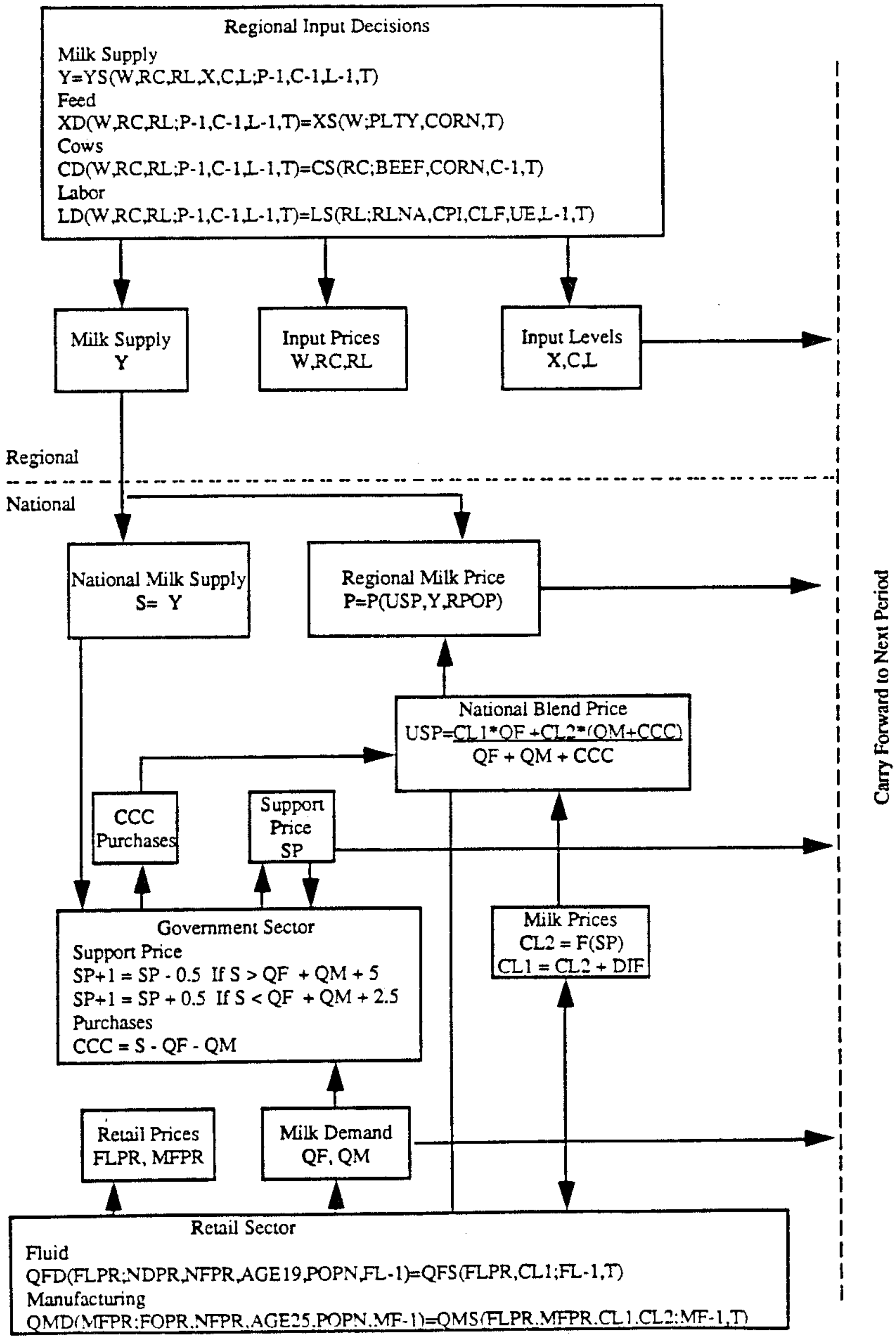

Figure 1.- Outline of U.S. Dairy Sector Model

TABLE 1: VARIABLE DEFINITION

Y	Regional milk supply
X	Quantity of dairy concentrate fed
W	Dairy concentrate price
C	Number of milk cows
R_c	Price of milk cows
L	Number of labour units in dairy sector
R_L	Agricultural wage rate
T	Time trend
P	Regional blend price for milk
CORN	Price per bushel of corn
PLTY	Price of poultry concentrate
BEEF	Price of beef cows and dairy cattle sold for slaughter
RL_{NA}	Manufacturing hourly wage rate
CLF	Size of civilian labour force
UE	Unemployment rate
S	National milk supply
QF	Equilibrium quantity of fluid milk products
FLPR	Retail price of fluid milk
NFPR	Price index of non-food items
NDBPR	Price index of non-dairy beverages
AGE19	Proportion of population under the age of 19
POPN	Total U.S. population
QM	Equilibrium quantity of manufactured milk products
MFPR	Retail price of manufactured milk products
FOPR	Price index of fats and oils
AGE25	Proportion of population between 25 and 49
CL1	Class I milk price
CL2	Class II milk price
DIF	Differential between Class I and Class II milk price
P	Regional blend price for milk
USP	National blend price for milk
CCC	Government purchases of manufactured dairy products
SP	Government support price
RPOP	Regional population

response is captured by including lagged supply for the quasi-fixed inputs of cows and labor. A linear functional form is used for all three input supply equations.

The model is closed through the specification of milk demand which is determined at the national level. In a method similar to that employed by Kaiser, Streeter, and Liu, milk demand is disaggregated into a fluid and manufacturing sector. Milk processors are assumed to be profit maximizers who produce either fluid (QFS) or manufactured dairy products (QMS). The supply of these products will depend on the respective retail prices, FLPR and MFPR, as well as the appropriate input price. This input price to the processors, which is also the price paid to the farmer, will be the Class I (CL1) for fluid milk and the

Class II (CL2) for manufactured dairy products. The effect of capacity constraint is accounted for through the inclusion of lagged supply.

The quantity demanded of fluid (QFD) and manufactured (QMD) dairy products is determined by the utility maximizing behaviour of consumers. Again employing a linear functional form, the demand for the two kinds of dairy products are specified to be dependent upon own and substitute prices, as well as demand shifters such as population and demographic factors. An increase in total U.S. population is assumed to increase demand for both goods but the increase will be modified depending upon age distribution.

As opposed to the behaviourial equations discussed thus far, the equations specifying the government sector of the model are identities determined by present government policy. The support price is adjusted based on the predicted difference between total milk supply and retail demand. If supply exceeds demand, the government purchases the surplus (CCC) at the previously announced support price. By increasing the demand for manufactured dairy products, the government implicitly increases the Minnesota-Wisconsin (M-W) price for manufactured grade milk. Thus, the Class II price (CL2) is formulated as linear function of the support price (SP) and the Class I price (CL1) calculated as the Class II price plus a fixed cost differential (DIF). Given the prices paid for raw milk by each of the retail sectors (CL1 and CL2) and the equilibrium amount of fluid (QF) and manufactured dairy products (QM), the national all milk price (USP) can be determined through the pooling procedure given in Figure 1.

There are two linkages between the regional and national levels of the model. The first is the calculation of national milk supply by the summation of milk production in each of the four regions. The quantity supplied, along with retail demand and government policy, determine the average national milk price. The second link uses this national milk price to connect the national part of the model back to the regional level. It is assumed that regional milk price (P) is a linear function of national milk price (USP) plus an adjustment based on the extent of surplus production within the region as measured by the ratio of regional population (RPOP) to milk supply. The year to year linkages within the model result from the inclusion of lagged endogenous variables.

The independence of the regional system of seven equations from the other regions and from the national market is achieved through the assumption of myopic milk price expectations by producers. The use of lagged milk price in the production decision permits regional milk supply to be estimated independently since output is determined on the basis of variables calculated from within each region. If current milk price was used, the block recursive nature of the system would be lost because milk price influences output and the level of output, would in turn, simultaneously determine milk price.

Four regions are delineated within the context of the USDA's regional production areas based on the importance of these regions to the national dairy sector and on the importance of dairy farming to the region itself. The top six milk producing states belong to three regions, the Northeast, Lake states, and Pacific, and together these regions produce 65 percent of the national milk supply. The three regions also are the ones in which production shifts will occur according to the OTA report and by Fallert et. al.. As a consequence, the paper focuses on the Northeast, the Lake States, Pacific and an aggregate of the remaining seven regions termed All Other.

Estimation and Ex Ante Simulation Results

The behaviourial equations within each subsector of the model were estimated simultaneously using nonlinear three stage least squares. The signs of the estimated coefficients were consistent with the theory on which they were based; the only exception being the inverse relationship found between feed concentrate supply and own price. The parameter estimates were then used to calculate elasticity measures and adjustment rates which were within the ranges obtained by previous studies. Based on these coefficients, historical and ex post simulations were conducted to examine the model's ability to track the movements of the endogenous variables. Given an average root mean square percentage error of less than 5 percent, the model was deemed appropriate to perform an ex ante forecast.

The model is simulated for three different future scenarios regarding the rates of technical change. The effects of technical change are incorporated in the model through a time trend which increases by an annual increment of one. In the initial scenario, the time trend is assumed to continue moving at this rate. The other two scenarios change the rate of productivity increase by augmenting the time trend variable in the milk supply equation by 16 and 32 percent respectively. It is assumed that these technologies are adopted following a logistic growth curve starting in 1990.

However, before the model can be used to forecast future endogenous variables, values for the exogenous variables must be predicted over the simulation period. The farm commodity prices were assumed to follow a five year moving average increasing by 2 percent a year. Non-agricultural prices were assumed to increase at annual rate of 4 percent. Regional and national population forecasts are the summation of state projections provided in the Statistical Abstracts of the United States. The final exogenous variable, unemployment, was assumed to follow a five year moving average.

Regional Production Shares

To highlight the distributional effects of technical change, the estimated variables under the alternative rates of productivity increase are assimilated into two key measures. The first of these is contained in Table 2 which summarizes the changes in regional production shares under each of the three scenarios. With no additional increases in productivity, the structural changes in the dairy sector continue to evolve at historical trends. The traditional milk producing regions of the Northeast and Lake States maintain their share of national supply at approximately 21 and 30 percent respectively. These figures increase slightly during the early 1990's when total milk supply is cut back in the All Other region. The effect of the reduction is to lower regional milk share from 35 to 31 percent in this region. However, during the latter years of the simulation, the All Other region is able to maintain its market share while the shares attributable to the traditional milk producing regions drop slightly. Although the Northeast and Lake States are increasing actual production, their relative increase is not as great as the remaining two regions. In contrast, the Pacific region continually increases its portion of the national market from 15 percent to approximately 18 percent by the turn of the century. The movement is steadily upward whereas the shares from the traditional milk producing regions rise only when low milk prices force a significant reduction from the All Other region.

Table 2: Regional Production Shares of National Milk Supply

	No Additional Increase in Productivity				16 % Additional Increase in Productivity				32 % Additional Increase in Productivity			
Year	Northeast	Lake States	Pacific	All Other	Northeast	Lake States	Pacific	All Other	Northeast	Lake States	Pacific	All Other
1988	.206	.292	.156	.346	.206	.292	.156	.346	.206	.292	.156	.346
1989	.209	.299	.158	.334	.209	.299	.158	.334	.209	.299	.158	.334
1990	.210	.298	.160	.332	.209	.299	.160	.332	.209	.299	.161	.332
1991	.212	.304	.164	.320	.212	.305	.163	.320	.213	.307	.159	.321
1992	.215	.309	.161	.315	.214	.311	.167	.308	.216	.316	.163	.305
1993	.220	.306	.164	.310	.216	.310	.167	.307	.211	.324	.169	.295
1994	.220	.304	.166	.310	.216	.306	.177	.301	.218	.316	.180	.286
1995	.214	.299	.170	.317	.223	.314	.172	.291	.222	.320	.178	.281
1996	.215	.297	.172	.316	.222	.318	.179	.282	.222	.326	.181	.272
1997	.216	.296	.176	.312	.222	.313	.180	.286	.230	.338	.181	.251
1998	.215	.301	.173	.312	.223	.314	.180	.284	.229	.344	.185	.241
1999	.212	.299	.175	.314	.216	.316	.181	.287	.227	.339	.182	.252
2000	.214	.295	.177	.315	.216	.314	.183	.287	.222	.334	.188	.255

The pattern is accentuated for the two scenarios involving additional increases in productivity. The new technologies spur milk production especially in the three major milk producing regions of the country. The resulting surplus is eventually corrected through a reduction in the support price, but the supply reduction only occurs in the All Other region. As a consequence, its regional production share falls by another 3 percentage points under scenario 2 and by 7 percentage points under scenario 3. In both cases, the additional drop in market share from the All Other region is divided evenly among the major milk producing regions.

Regional Net Income

Another measure of the distributional effects of technical change is the changes in regional net income. Table 3 gives regional net income as a percentage of actual income in 1986 with net income calculated as gross revenues from milk production less the input costs of feed, cows, and labour. All variables necessary to determine income are generated within the simulation model. Revenue is equal to milk price multiplied by supply. Similarly, input costs are derived by multiplying the quantity and price figures for each of the respective three inputs.

Income is generally reduced across all regions during the late 1980's due largely to the effect of lower milk prices. Under scenario 1, the trend is reversed in 1993 at which time the effective milk price rises. Milk supply in the traditional milk producing regions breaks out of its horizontal trend and the increased production in combination with higher milk prices significantly raises revenue during the mid 1990's. Total costs are generally reduced over time given the fall in the number of quasi-fixed inputs so the net effect is an increase in net income for the major milk producing regions. During the late 1990's an increase in milk supply allows income to remain above 1986 values for the Lake states region while an increase in herd size forces income down in the Pacific despite an increase in production. The reduction in milk supply in the All Other region forces income levels down from their 1986 values. Income falls each successive year despite an increase in both price and production beginning in 1996. Increased feed and labour costs during these latter years keeps relative income values falling.

The adoption of output enhancing technologies alters the annual changes in net income levels. Assuming new technology causes a 16 percent additional increase in productivity, the traditional milk producing regions continue to increase supply despite a fall in milk price. The eventual increase in milk price is again brought about by a reduction in supply from the All Other region as was the case in the base scenario. The increase causes a subsequent increase in relative income levels during the early 1990's. However, milk prices never attain the levels reached under scenario 1 due to the

Table 3: Percentage Changes in Regional Dairy Net Income From Actual 1986 Values

	No Additional Increase in Productivity				16 % Additional Increase in Productivity				32 % Additional Increase in Productivity			
Year	North East	Lake States	Pacific	All Other	North East	Lake States	Pacific	All Other	North East	Lake States	Pacific	All Other
1987	-117.7	-139.3	-594.5	15.7	-117.7	-139.3	-594.5	15.7	-117.7	-139.3	-594.5	15.7
1988	-57.8	-117.8	-387.5	-4.3	-57.8	-117.8	-387.5	-4.3	-57.8	-117.8	-387.5	-4.3
1989	-94.6	-37.3	-596.2	-12.9	-94.6	-37.3	-596.2	-12.9	-94.6	-37.3	-596.2	-12.9
1990	-25.9	-65.0	120.8	-46.8	-25.5	-63.2	138.5	-46.9	-23.7	-60.6	165.0	-47.2
1991	-41.0	-90.8	-90.0	-45.9	-36.0	-80.8	-223.5	-47.0	-31.0	-70.8	-377.8	-48.1
1992	-36.8	-85.9	-308.5	-53.1	-23.9	-59.6	-158.0	-54.1	-31.2	-69.4	-399.2	-32.1
1993	45.7	-38.7	66.7	-60.1	41.3	-20.1	99.1	-66.1	8.1	-21.9	15.9	-61.7
1994	110.3	30.0	603.7	-70.0	21.0	-92.1	-37.6	-58.0	36.2	-69.3	64.7	-68.1
1995	100.6	53.9	1276.9	-71.1	-25.2	-108.8	11.8	-54.9	-10.3	-87.3	67.3	-64.5
1996	81.4	102.9	1382.7	-87.3	-53.0	-51.7	63.9	-68.1	-118.6	-150.0	-614.1	-60.8
1997	42.4	137.7	1194.8	-95.7	-76.8	-5.8	-93.8	-76.0	-158.5	-123.3	-1130.4	-69.7
1998	67.1	153.6	567.4	-110.5	-67.3	0.1	-462.3	-93.0	-135.8	-98.1	-1131.6	-76.5
1999	30.7	158.1	-704.2	-102.6	-102.4	32.8	-1120.3	-95.3	-92.0	-23.2	-1379.6	-90.8
2000	24.5	158.3	-1369.0	-102.2	-132.4	48.0	-1662.7	-100.2	-49.1	-12.3	-1633.8	-100.2

technology's impact on total output. Income levels fall as a result during the latter years of the simulation, except in the Lake states where a jump in supply combined with a large drop in cow numbers serves to increase net income. In contrast, cow numbers rise in the Pacific region for the late 1990's and this acts to severely reduce income at that time.

The effect is magnified with a 32 percent additional increase in productivity. The large increase in output requires annual reduction in the support price until 1996. Unlike the previous two scenarios, the drop in supply is not borne exclusively by the All Other region. The large drop in milk price eventually forces the traditional milk producing to also cut back production during the mid-1990's. Only in the Pacific region is the increase in output sufficient to raise income. However, this region's income eventually falls during the latter years due to smaller increments in milk supply and slow adjustments in cow numbers. In contrast, the cut back of quasi-fixed inputs and increase in milk price reverses the direction of net income during these latter years for the traditional milk producing regions.

Comparing the impacts of new technology across the alternative scenarios reveals that the major milk producing regions would benefit most from a continuation in the present trend of productivity increase. Income levels increase with productivity enhancement in the initial years of the new technology. Output is expanded without any corresponding increase in costs or reduction in milk price. However, the extent of the additional supply then forces down milk price to a greater degree and longer extent than with base scenario. The result is a reduction in regional income values for any given year as the rate of productivity growth increases.

There are exceptions to this general conclusion. The most notable is the All Other region where net income is generally higher under a 16 percent additional increase in productivity. The result is brought about by a large reduction in the quasi-fixed inputs relative to the base scenario and the larger gross revenues attained in comparison to scenario 3. In contrast, large relative drops in cow numbers and labor occurs in the Northeast region with a 32 percent additional increase in productivity. The resulting lower costs translate into a higher net income level in comparison to scenario 2 for the latter years of the simulation. Higher incomes levels are also attained for scenario 3 in relation to scenario 2 in the Pacific region but only for 1994 and 1995. It is those years in which the new technology is most rapidly adopted. This large effect on supply is greatest for the Pacific region and translates into higher income levels than for scenario 2 since prices and input levels have not had sufficient time to adjust.

Conclusions

A dynamic general equilibrium model of the U.S. dairy sector was constructed and used to examine the future distributional effects of technical change in the dairy sector. In contrast to studies which have relied upon analyzing economic costs of typical farms, this model forecasts the historical trends in regional structure will continue to persist until the end of the century. The traditional milk producing regions of the Northeast and Lake States will maintain their share of national output while the Pacific region increases its share at the expense of the All Other region. As the rate of productivity enhancement increases, the resulting fall in milk prices curtails production increases in all regions with the largest cutback coming from the amalgamation of the remaining seven USDA farm production regions. The extent of the reduction in this All Other region allows the traditional milk producing regions to increase production shares. However, the increase in market share does not translate into higher income levels.

The use of dynamic duality to construct the producer core equations allows accounting for the production characteristics and adjustment responses of each region which were not captured by previous accounting studies. Regional adjustment is especially relevant given the present policy of tying changes in the support price to the relationship between market demand and supply. If the policy is adhered to, government purchases can be significantly reduced or even eliminated. However, the cutback in milk supply occurs largely outside of the three major milk producing regions of the Northeast, Lake States and Pacific region. As a result, programs which aid the exit of producers in the seven other regions will speed the adjustment process and prevent large drops in net dairy farm income.

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