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STRUCTURAL ADJUSTMENT IN OECD AGRICULTURE: GOVERNMENT POLICIES AND TECHNICAL CHANGE

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1. INTRODUCTION

Government policy towards agriculture has been subject to a great deal of scrutiny during recent years in a number of contexts, especially the Uruguay round of GATT negotiations. There is an emerging concensus that individual countries (or blocs of countries) ought to reduce total support for agriculture and, in particular, that support mechanisms ought to be less trade-distorting. Against the benefits from reducing support (or reinstrumentation) must be balanced the costs of adjustment as resources are required to be reallocated in response to changing policies. The issue of structural adjustment-its determinants and its implications-is, for those reasons, of increasing concern among OECD governments contemplating policy reform.

Structural adjustment has been a continuing feature of OECD agriculture. Indeed, the issue of structural change and policies to mitigate its effects has been at the heart of agricultural policy in most OECD countries. In some cases this issue has been referred to as the Farm *Problem*-"... a problem of low and unstable incomes, generated by the particular structure of the agricultural sector. " (Gardner 1992, p. 63) In the present context structural adjustment pertains to the farm problem in terms of the causes and consequences of changes in the quantities and prices of agricultural inputs and outputs, and therefore changes in factor incomes and personal incomes in rural areas.

The three primary causes of structural change in agriculture can be identified as (a) changes in the supply of factors of production (labour, land, and capital, etc.) to the agricultural sector, either due to changes in total supply to the entire economy or changes in demand from the nonfarm economy (e.g., nonfarm demand bidding up the cost of labour to the agricultural sector); (b) changes in the demand for agricultural products (e.g., growth in total demand due to income growth or changes in the pattern of demand due to income growth or demographic change); and (c) changes in the technology of agricultural production. The first two (changes in factor supply or output demand) are largely exogenous to agriculture whereas the third, changes in the choice of technology, may be determined more within agriculture.

Government policy has impacts at every level. From the perspective of farmers, commodity policies typically have their primary impacts on the demand facing farmers for their products; other policies, such as macroeconomic policies, might have their primary impacts through factor markets (e.g., nonfarm wages and interest rates); research and technology policies have their primary impacts through the availability of technological options and on incentives for adoption of technology.

It is an oversimplification to treat these three primary causes of structural change as independent of one another. One important question about commodity policy is whether it has a significant longer-run impact on agriculture through changes in incentives to develop and adopt new technology, in addition to its shorter-run allocative impacts, and whether the technological effect is as important as (or more important than) the allocative effect which has been afforded greater attention by economists. For instance, Mellor and Johnson (1984, p. 558) suggested that "... the indirect, long-term effects of price distortions on the orientation of research and the bias of technical change may well be more important than their adverse effects on short-run allocative efficiency. Understanding the extent to which past structural change in agriculture was an allocative response (and therefore largely reversible) as opposed to being an induced technological response (and therefore largely irreversible) is a fundamental question of central concern to those who wish to understand the structural implications of policy reform.

With such issues in mind, the purpose of the present paper is to review the existing literature on the effects of commodity market distortions on incentives for research and development, and adoption of technology, in agriculture, with an emphasis on the OECD countries. The analysis begins (in section 2) with a review of the major patterns of structural change characterizing OECD agriculture during the recent past-looking at changes in output, input use, and measures of partial factor productivities and total (or multi-) factor productivity-and some speculation about the likely causes of those general trends. The subsequent section of the paper (section 3) formalizes that speculation using a simple model. The conclusion of the analysis in those two sections is that technological change in agriculture occupies the centre stage of any discussion about structural change in agriculture. These two sections (sections 2 and 3) are primarily background motivation for the next section, in summary form (it is understood that more detail on these aspects will be developed independently at OECD). Section 4 is the main contribution of the paper. It presents the theory and evidence from the literature on the impacts of market-distorting policies for the development and adoption of **new** agricultural technology. Section 5 draws implications for future work and concludes the paper.

2. STRUCTURAL CHANGE IN OECD AGRICULTURE, 1960-1985.[1]

2.1 Introduction

Agricultural production in OECD countries has grown hugely in the post-war period. For instance, Pardey, Craig, and Deininger (1993) estimated that aggregate U.S. agricultural output grew at an annual rate of 1.58 percent between 1949 and 1985, an increase of 78.7 percent over the 35-year period. Some of that growth has involved increases in factor use (especially mechanical inputs and chemicals), but a great part of it has been in spite of the reductions in the use of labour (and to a lesser extent land) in agriculture. Again, considering the U.S. example, Pardey, Craig, and Deininger (1993) estimated that aggregate inputs used by U.S. agriculture grew at an annual rate of only 0.40 percent between 1949 and 1985.

The growth in output that cannot be attributed to greater input use (i.e., what we call productivity growth) is attributable to technological change driven by public- and private-sector R&D. In the U.S. case, total factor productivity was estimated to have grown at 0.79 percent per year between 1949 and 1985 (Pardey, Craig, and Deininger 1993).[2] There is some disagreement in the literature about the details of the measurement, but there is no disagreement with the view that (a) firstly, productivity in agriculture has grown much more quickly than productivity in the nonfarm economy and (b) secondly, productivity growth has accounted for the lion's share of output growth in agriculture (e.g., Jorgenson and Gollop 1992).

Agricultural productivity has been studied extensively, and a variety of total or partial factor productivity measures have been used.[3] Whatever measure is used, estimates of agricultural productivity vary widely across countries.

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[1]The discussion of changes in structure here is somewhat discursive in recognition of the ongoing work at OECD that will be documenting the historical trends in greater detail. The idea is to indicate in this paper only the broad trends in the key variables and to provide greater detail on the productivity growth aspects, and R&D, that will not be covered in as much depth in the OECD work.

[2]As discussed below, other studies have obtained much greater estimates of total factor productivity growth in U.S. agriculture than Pardey, Craig, and Deininger (1993) did.

[3]For a review of measurement issues and theoretical explanations of productivity changes, see Capalbo and Antle (1988).

Partial Factor Productivity Measures

Table 2.1 shows partial productivity measures, for land and labor, for the 22 OECD countries and for the OECD in aggregate, for the period 1961-65 to 1986-90. It also includes a compound annual growth rate for each of the factor productivity measures. As would be expected, given their endowments of land and labour, *Labour productivity is relatively high for Au*stralia, New Zealand and the United States, and relatively low for Japan. It is of interest also to note that labour productivity is also relatively high for the Netherlands (higher than in the United States and Australia), Belgium-Luxembourg, and Denmark; it is relatively low for Turkey, Portugal, and Greece as well as Japan. For the OECD as a whole, labour productivity has grown at an average annual rate of 4.0 percent during 1961-65 to 1986-1990. There has been significant variation around that average among countries, as can be seen in table 2.1. Also as would be expected, *Land productivity* has been highest in the Netherlands, followed by Japan, and then the other European regions, and lowest in Australia. Land productivity has grown too, but not as rapidly as labour productivity. The average annual growth rate across the OECD countries was 1.6 percent during 1961-65 to 1986-1990; it ranged from a high of 2.85 percent in Australia to a low of -0.10 percent in Japan.

The changes in partial factor productivities reflect the influence of both technological change and changes in the factor mix-typically a reduction in the labour in agriculture relative to land and, with fairly constant total land-use in agriculture, essentially that means a reduction in the use of labour; at the same time, the use of capital has tended to grow slightly over time. Table 2.2 shows the land-labour ratios for the individual OECD countries and for the OECD in total, calculated as five-year averages from 1961-65 to 1986-90.

Land-labour ratios (hectares per unit of labour) vary among OECD countries from a high of 1126.2 in Australia to a low of 1.2 in Japan, with an OECD average of 39.0 (1986-90 figures). **The** average OECD land-labour ratio almost doubled from 21.4 in 1961-65 to 39.0 in 1986-90. Some countries showed much greater growth in the land-labor ratio (notably Japan and Canada) while for others it was constant (Australia and New Zealand) and in one case (Turkey) it actually fell. In addition, table 2.2 shows annual average growth rates in the land-labour ratios for 10-year intervals, and for the entire 30-year period. The 30-year average rate was 2.4 percent and the rate did not vary much from that in the individual decades.

Table 2. I : Agricultural Land and Labor Productivities, 1961-90

Country	1961-65	1966-70	1971-75	1976-80	1981-85	1986-90	Annual average growth[a]	1961-65	1966-70	1971-75	1976-80	1981-85	1986.90	Annual average growth[a]
			(output per unit of labor)				%			(output per unit of land)				%
Australia	18117	22755	25147	27200	29121	34182	3.41	18	21	23	26	27	30	2.85
Austria	3062	4484	5927	8029	10851	13336	5.74	532	593	638	728	828	853	1.52
Belgium-Luxembourg	11397	15379	21457	25630	35348	49216	6.01	1655	1791	2071	2114	2424	2757	2.01
Canada	10540	13436	14884	17731	22548	28528	4.94	139	150	149	163	169	172	1.58
Denmark	9708	11663	13756	17244	24462	32864	5.23	1082	1115	1143	1248	1495	1702	2.10
Finland	2471	2956	3823	5057	6584	7760	4.90	465	485	533	577	652	667	1.68
France	5585	7438	9752	12325	16730	20848	5.37	648	719	800	850	947	980	1.69
Germany, Federal Republic	4420	6978	9073	10479	13568	17819	5.85	1097	1227	1351	1449	1637	1758	1.89
Greece	1839	2302	3080	3920	4862	5367	3.75	346	381	448	507	570	576	1.48
Ireland	4965	6630	9055	12052	13730	16919	4.80	326	369	437	516	528	582	2.09
Italy	2692	3952	5220	6902	9330	11523	5.65	744	851	1034	1116	1225	1238	1.68
Japan	1238	1534	1685	2159	2705	3335	3.95	2819	2982	2759	2822	2756	2771	-0.10
Netherlands	12113	16595	21115	24040	31056	39585	4.87	2158	2549	3144	3610	4314	4759	3.14
New Zealand	27863	33116	33805	34655	38295	40038	1.35	279	326	342	352	380	392	1.29
Norway	3259	4047	4786	5604	7300	8694	3.81	805	838	952	1041	1129	1072	0.84
Portugal	1621	1891	2117	1790	1966	2703	3.17	469	476	481	431	428	484	1.13
Spain	2066	2831	4143	5771	7475	9840	6.35	274	301	360	436	483	541	2.66
Sweden	4581	5745	7475	9347	12171	13311	4.55	474	515	571	630	715	694	I.85
Switzerland	5116	6217	7289	9078	11095	13528	3.76	631	675	763	879	955	985	1.50
Turkey	740	830	942	1154	1240	1342	2.32	220	247	281	337	385	430	2.56
UK	9941	12887	15686	17037	20923	23807	3.57	464	515	5%	655	762	785	2.03
USA	17603	22026	25677	28601	32649	37394	3.36	181	198	222	254	269	265	1.70
Average OECD	3996	5077	6235	7699	9281	10578	4.0	187	203	220	244	263	271	1.6

Nore: See note to figure 2.1 for construction details. Output represents gross agricultuml output in 1980 agricultural Purchasing Power Parity (PPP) dollars.

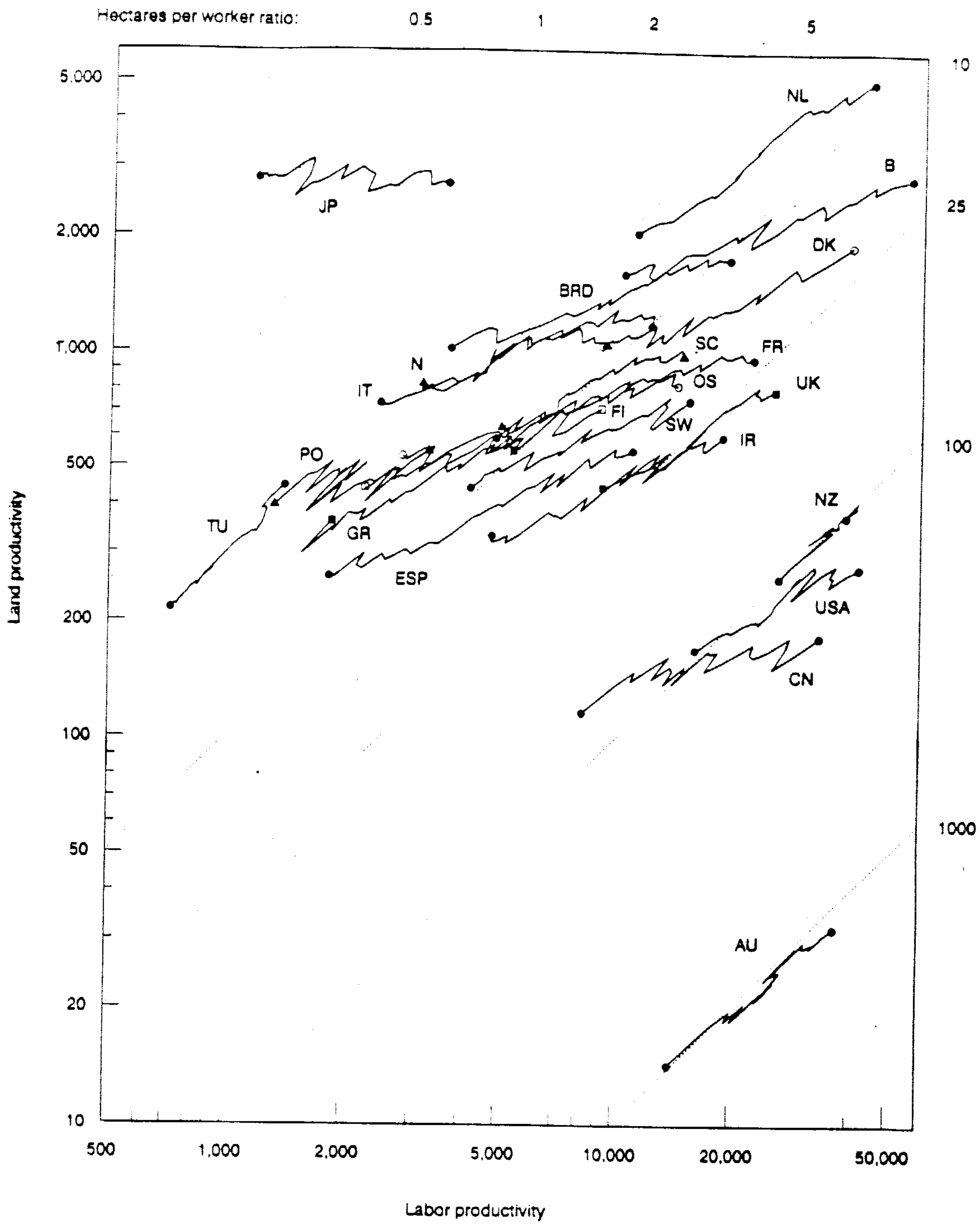
[a]Compound annual growth rate for the period 1961 to 1990.

Table 2.2: ***Land-Labor Ratios in Agriculture, 1961-90***

	1961-65	1966-70	1971-75	1976-80	1981-85	198690	Annual average growth 1961/70	1970/80	1980/90	1961/90
	(hectares per unit labor)						%	%	%	%
Australia	1010.6	1096.4	1110.4	1047.8	1059.7	1126.2	1.5	-0.7	1.0	0.5
Austria	5.8	7.5	9.3	11.0	13.1	15.6	5.4	3.6	3.6	4.2
Belgium-Luxembourg	6.9	8.6	10.4	12.1	14.6	17.8	4.3	3.1	4.4	3.9
Canada	75.3	89.7	99.6	109.1	133.7	166.2	3.5	2.1	4.4	3.3
Denmark	9.0	10.5	12.0	13.8	16.3	19.2	2.9	2.8	3.5	3.1
Finland	5.3	6.1	7.2	8.8	10.1	11.6	2.8	3.9	2.8	3.2
France	8.6	10.3	12.2	14.5	17.6	21.3	3.4	3.6	3.8	3.6
Germany, FR	4.0	5.7	6.7	7.2	8.3	10.1	6.5	1.7	3.8	3.9
Greece	5.3	6.0	6.9	7.7	8.5	9.3	2.4	2.4	1.8	2.2
Ireland	15.2	18.0	20.7	23.3	26.0	29.1	3.3	2.5	2.3	2.7
Italy	3.6	4.6	5.0	6.2	7.6	9.3	4.9	2.8	4.2	3.9
Japan	0.4	0.5	0.6	0.8	1.0	1.2	3.2	4.5	4.4	4.1
Netherlands	5.6	6.5	6.7	6.7	7.2	8.3	2.7	-0.2	2.7	1.7
New Zealand	180.0	101.6	98.9	98.4	100.9	102.2	0.2	-0.3	0.3	0.1
Norway	4.0	4.8	5.0	5.4	6.5	8.1	3.2	1.2	4.5	2.9
Portugal	3.4	4.0	4.4	4.2	4.6	5.6	2.7	-0.3	3.8	2.0
Spain	7.5	9.4	11.5	13.2	15.4	18.2	4.4	3.2	3.3	3.6
Sweden	9.7	11.1	13.1	14.8	17.0	19.2	2.8	2.6	2.5	2.6
Switzerland	8.1	9.2	9.6	10.3	11.6	13.7	2.3	1.0	3.4	2.2
Turkey	3.4	3.4	3.4	3.4	3.2	3.1	0.1	0.3	-1.0	-0.2
UK	21.4	25.0	26.3	26.0	27.4	30.3	2.7	0.1	1.9	1.5
USA	97.1	110.9	115.5	112.4	121.6	141.2	2.4	-0.3	2.9	1.6
Average OECD	21.4	25.0	28.3	31.5	35.2	39.0	3.0	2.2	2.1	2.4

Note: See note to figure 2.1 for construction details.

Figure 2.1: *Agricultural land and labor productivities in OECD countries, 1961-90.*



Legend: AU = Australia; OS = Austria; B = Belgium; CN = Canada; DK = Denmark; FL = Finland; FR = France; BRD = West Germany; GR = Greece; IR = Ireland; IT = Italy; JP = Japan; NL = Netherlands; NZ = New Zealand; N = Norway; PO = Portugal; SP = Spain; SW = Sweden; SC = Switzerland; TU = Turkey; UK = United Kingdom; USA = United States.

Note: Labor productivity measures gross agricultural output relative to the economically active agricultural population and land productivity is gross output per unit of arable plus permanently cropped or permanently pastured land. Gross agricultural output for 1980 was derived in agricultural purchasing power parity dollars using data from FAO (1986), and then backcast and extrapolated forward using country specific agricultural production indices reported in FAO (1990).

The general tendency to increase the land-labour ratio reflects primarily the egress of labour from farming (total land-use has been fairly constant). Behind that movement of labour out from agriculture there have been two major forces: (a) the *push* from the introduction of labour-saving (primarily mechanical) technologies, and (b) the ***pull*** from the rise of nonfarm wages drawing labour from agriculture and causing a substitution of other inputs (land, capital, and purchased inputs) for labour. To some extent the first effect might have been an induced-innovation response, too, rather than an autonomous development. A variety of types of technical changes may underly these changes in factor mix and factor productivities, including changes in techniques, genetic improvements, changes embodied in mechanical inputs, and changes in the stock of knowledge (as distinct from changes in human capital due to education)

Figure 2.1 combines graphically the information on marginal productivities of land and labour (from table 2.1) and the information on land-labour ratios (from table 2.2). On this figure the horizontal axis measures labour productivity, the vertical axis measures land productivity, and the dotted (45-degree) lines represent constant land-labour ratios. Consider the case of Australia depicted in the lower right-hand comer. The graph shows that both land and labour productivity rose, and that the land-labour ratio was almost constant, between 1961 (the lower endpoint) and 1990 (the upper endpoint). A longer graph indicates a greater growth in productivity (e.g, the Netherlands, NL, in the upper right-hand comer) and a shorter one represents a smaller overall growth in productivity (e.g., New Zealand, AZ, half-way up the graph). A flatter graph indicates a greater substitution of labour for land (e.g., see Japan, ***JP,*** in the upper left-hand comer) and a steeper one indicates a substitution of land for labour (e.g., Turkey, TU). All of the OECD countries exhibited some productivity growth so that the lower/left-hand endpoints of the graphs in every case correspond to the beginning of the period.

Total Factor Productivities

There is less information available about total factor productivities in agriculture. Frisvold and Lomax (1991) report total factor productivities for 18 countries for 1970 and 1980 and the annual productivity growth rates over that time period. Their growth rates range from a high of 3.22 percent in the Netherlands to a low of -2.66 percent in Peru.

Table 2.3: Total Factor Productiviry Growth Rates for U.S. Agriculture

Period	Ball	Capalbo & Vo	Huffman & Evenson	Pardey, Craig & Deininger	Jorgenson & Gallop
	%	%	%	%	%
1949-55	2.56	1.18	2.04	0.65	1.37 (1947-53)
					2.33 (1953-57)
1955-60	2.75	1.19	2.46	0.79	1.35 (195760)
1961-65	2.54	1.16	2.66	0.62	0.63 (1960-66)
1966-70	-0.07	0.42	1.18	0.79	1.19 (1966-69)
1971-75	2.83	2.69	1.53	0.90	-0.67 (1969-73)
1976-80	1.52	1.21	0.66	0.60	2.06 (1973-79)
1981-85		-0.71	2.13	1.47	3.58 (1979-85)
1949-85[a]	1.86	1.34	***1.84***	0.79	1.58

Source: Pardey, Craig and Deininger (1993) and Jorgenson and Gollop (1992).

[a]For Ball the relevant period is 1949-79, for Capalbo and Vo it is 1949-83, for Huffman and Evenson it is 1949-82, and for Jorgenson and Gollop it is 1947-85.

Pardey , Craig, and Deininger (1993) report total factor productivity growth rates for U.S. agriculture as a whole, for regions, and for 5-year periods, from 1949 to 1985. They compared their results with those from stdies by Ball (1985), Capalbo and Vo (1988), and Huffman and Evenson (1993). Table 2.3 combines those results from Pardey, Craig, and Deininger (1993) and those from Jorgenson and Gallop (1992). It can be seen in table 2.3 that the other studies have obtained much greater estimates of total factor productivity growth in U.S. agriculture than Pardey, Craig, and Deininger (1993) did. The other studies found annual average total factor productivity growth rates for 1949-85 of between 1.3 and 1.8 percent whereas Pardey, Craig, and Deininger (1993) estimated a rate of only 0.79 percent. The critical differences in the calculations, apparently, are in the indexing procedure for the measurement of total output, in the adjustment of labour quantities to reflect changes in labour quality, and in the adjustment of capital quantities to reflect changes in the quality of capital, particularly machinery.

There are few comparable studies for other countries. Boyle (1987) estimated a total factor productivity growth rate for the Irish farm sector of 1.1 percent per year over the period 1975-82, and more recently he estimated a corresponding productivity growth rate of 1.9 percent per year for the period 1973-90 in the Irish farm sector. Scobie, Mullen and Alston (1991) summarize the results of a number of studies of productivity growth in the Australian sheep industry that indicate productivity growth rates of between around 1 and 3 percent per year between 1953 and 1983, and another set of studies that document estimates of productivity growth in Australian agriculture more broadly defined (the estimates range from 0.5 percent to 4 percent per year). Underlying this range of estimates is a range of estimation procedures.

The total factor productivity studies use index number procedures to account for sources of growth. Some other studies have measured the contribution of technologicalchange to total output growth using econometric methods. For example, Bouchet, Orden and Norton (1989) applied a multi-output profit function approach to French agriculture (representing almost 30 percent of EC farm production and a greater share of EC farm exports). They reported growth in production of livestock products of about 65 percent, and growth of production of plant products of about 86 percent, between 1960 and 1984, an outcome which arose in spite of falling output prices and rising labour prices. For the examples of milk and cereals, they found that French public-sector agricultural research accounted for 43 percent and 207 percent of the total growth, respectively (i.e., in the case of milk, output would have fallen without the research); in addition international technology availability accounted for 94 percent and 11 percent of growth of milk and cereal production, respectively. Putting the two together, technological change arising from French research or international technology transfers accounted for more than 100 percent of the total growth in production of both milk and cereals. As a result of technical change, French agricultural output grew by well over 50 percent, despite falling output prices and rising labour costs. Without the technical change, French agricultural output would have fallen.

2.4 Agricultural Research Expenditures and Research Intensities

There is no clear concensus in the literature on the determinants of agricultural productivity. In the forword to Capalbo and Antle (1988), Farrell wrote:

> "A substantial body of research results on agricultural productivity exists, but it lacks comprehensive assessments of the sources of growth and the public policy implications of possible future growth. With few exceptions, empirical research on productivity has focused on historical assessments of growth rates and measurement of structural indicators....Generally, however, that research has been highly aggregative and only partially successful in isolating the relative effects of a variety of possible determinants of productivity change."

However, there is a concensus that agricultural research effectively enhances productivity and that locally adapted agricultural research is **a** crucial determinant of productivity (e.g., Hayami and Ruttan 1985, Mellor and Johnson 1984). Thus, Alston and Pardey (1993) argued, understanding the causes of investment in agricultural R&D is crucial to understanding the pattern of international agricultural productivity differences. **A** first step is to document the pattern of investments in agricultural R&D.

Table 2.4 shows estimates of public-sector agricultural research expenditures in the twenty-two OECD countries in 1970,1980, 1985, and a most recent year (1990 for many cases). The figures are expressed in millions of 1985 (i.e., real) U.S. dollars. These figures show that public sector agricultural research is significant (e.g., around $2 billion per year in the United States), but modest compared with other elements of expenditure on agriculture (e.g., U.S. expenditures on farm programs or on food stamps, or the CAP expenditure). In addition, the table shows growth rates of research expenditures over the period from 1970 forward.

The problem with comparisons using the agricultural research spending data in table 2.4 is that the scale of countries varies. One useful way to make the data more comparable is to scale the research expenditure according to the size of the agricultural sector, measured by the value of production (agricultural GDP). Table 2.5 shows Agricultural Research Intensities (ARIs) for 1970, 1980, and 1985. The most significant feature in these data is the range in ARIs-in 1985 they range from over 5 percent of agricultural GDP being spent on public-sector R&D in Canada to less than one tenth of that percentage (0.44 percent) in Greece. Another important pattern in the data is a trend to increase research intensities over time, although the changes are small relative to the cross-sectional variation. Alston and Pardey (1993) suggested that income per capita and the importance of agriculture in the economy were the major factors acccounting for variation in ARIs among both less- and more-developed countries (including a larger sample of countries and a longer time series than is shown here). The patterns of data here are probably consistent with their results.

The picture of research intensities and their determinants is clouded by several factors. The data in tables 2.4 and 2.5 are incomplete in that they refer only to public-sector research and do not include private research expenditures. Private-sector agricultural R&D is large and growing, probably faster than the private-sector component as a consequence of improvements in property rights. Some segments are becoming dominated by private R&D. For instance, Huffman (1992) reports that the 1,249 scientists (full-time equivalents) engaged in plant-breeding research in the United States in 1989 included only 417 in the public-sector; the majority were employed as private breeders/geneticists (580) and private biotechnology research (252). The understatement of total research investments is probably greater for the larger industrialized countries, so that the differences in total research intensities are probably greater than the differences in public-sector research intensities among countries. In addition, the sources of funds for research investments and the nature of the research being undertaken are not known.

Table 2.4: Public Sector Agricultural R&D Expenditures for the ***OECD Countries***

	1970	1980	1985	latest year[b]		Growth rate 1970-80	Growth rate 1980-85	Growth rate 1970-85
	(millions *1985* US *dollars*)[a]					%	%	%
Australia	241.660	329.361	403.752	415.090	(1986)	3.14	4.16	3.48
Austria	18.984	20.063	22.519	-	(1985)	0.55	2.34	1.14
Belgium	26.335	46.607	-	44.244	(1981)	5.74	-	-
Canada	351.249	420.940	565.118	-	(1985)	1.83	6.07	3.22
Denmark	32.866	31.425	38.754	54.525	(1990)	-0.45	4.28	1.10
Finland	21.399	35.165	38.298	42.140	(1986)	5.09	1.72	3.96
France	143.460	245.205	275.666	373.790	(1990)	5.51	2.37	4.45
Germany	272.145	277.314	285.567	256.254	(1988)	0.19	0.59	0.32
Greece	-	22.467	38.607	41.035	(1988)	-	11.44	-
Iceland	3.094	5.513	4.500	5.294	(1987)	5.95	-3.98	2.53
Ireland	26.363	27.054	29.989	17.885	(1988)	0.26	2.08	0.86
Italy	85.334	122.623	267.376	378.218	(1988)	3.69	16.87	7.91
Japan	788.235	1090.039	1170.998	1122.593	(1990)	3.29	1.44	2.67
Netherlands	164.915	218.614	211.912	231.956	(1990)	2.86	-0.62	1.69
New Zealand	62.664	96.961	-	101.317	(1983)	4.46	-	-
Norway	33.227	53.837	62.345	-	(1985)	4.94	2.98	4.28
Portugal	23.435	28.539	28.558	37.298	(1988)	1.99	0.01	1.33
Spain	14.496	72.999	113.983	185.705	(1988)	17.55	9.32	14.74
Sweden	58.088	65.235	74.300	-	(1985)	1.17	2.64	1.65
Switzerland	31.767	21.076	29.886	30.315	(1986)	-4.02	7.24	-0.41
Turkey	59.143	56.965	-	65.142	(1981)	-0.37	-	-
United Kingdom	306.947	351.999	356.532	252.933	(1990)	1.38	0.26	1.00
United States	1387.095	1715.390	1912.656	2032.710	(1990)	2.15	2.20	2.16

Source: Pardey and Roseboom (1989) updated with data from Eurostat (1987 and 1990), Thirtle (1989), Rutten (1993), Pardey, Eveleens and Hallaway (forthcoming), INEA (1988 and 1990), Selostus (1987), OECD (1991), Burian (1992), Rost (1993), Laier (1993).

[a]Research expenditures in current local currency units first deflated to 1985 prices using local implicit GDP deflators taken from World Bank (1992) then converted to US dollars using purchasing power parity indices from Summers and Heston (1991).
[b]Year in brackets.

*Table 2.5: Agricultural **Research** Intensity Ratios*

country[a]	1970	1980	1985
	%	%	%
Canada	4.34	3.38	5.31
Australia	3.38	3.54	5.04
United Kingdom	2.36	3.34	3.77
Norway	1.99	2.94	3.62
Netherlands	2.64	4.18	3.26
New Zealand	2.07	3.07	--
Japan	1.83	2.70	2.80
Germany	1.65	2.03	2.30
United States	1.91	1.90	2.24
Belgium	1.11	2.24	--
Sweden	1.79	2.06	2.19
Iceland	1.06	2.08	1.63
Ireland	1.41	1.20	1.30
Denmark	1.36	1.22	1.29
France	0.51	0.99	1.13
Italy	0.28	0.38	0.98
Finland	0.57	0.85	0.97
Switzerland	--	--	0.89
Austria	0.54	0.62	0.87
Spain	0.09	0.45	0.77
Portugal	0.51	0.64	0.66
Greece	0.00	0.27	0.44
Turkey	0.29	0.21	--

Source: See table 2.4.

Note: These agricultural research intensity ratios measure nominal agricultural research expenditures as a percentage of the corresponding nominal Agricultural GDP taken from World Bank (1992).

[a]Countries ranked in descending order of 1985 ratio except for Belgium, New Zealand and Turkey whose ranking is based on their 1980 ratio.

2.5 Overview on Structural Change, Productivity and Agricultural R&D

The "facts" in this section have shown that there has been a great deal of growth in agricultural production that cannot be accounted for by growth in conventional inputs. This productivity growth may be accounted for primarily in terms of changes in input quality (especially changes in the quality of the human agent through education) and other, research-induced, technological change. Some of the change, however, is due to exogenous changes in demand and factor supply. Those relationships are explored more formally in section 3, which presents models of agricultural production and input use.

The "facts" have also shown that the pattern of productivity growth has not been uniform among countries nor over time. Why this is so cannot be answered fully here because our knowledge of the determinants of productivity growth remains, sadly, incomplete. Clearly, however, differences in investments in agricultural R&D among nations have contributed in part to the differences in performance of their agricultural sectors. Many economists hold the view that when markets are highly distorted (especially where the distortions are against agriculture) productivity, and productivity growth, will be low. However, there is little formal evidence on the effects of price distorting policies on productivity and productivity growth. It has been suggested by various writers (e.g., Fulginiti and Perrin 1991, Mellor and Johnson 1984, Schultz 1977, 1978) that these pervasive price distortions account in part (perhaps in great part) for the low rates of R&D investments and the low rates of productivity growth. The relationship between public and private investment in agricultural R&D and productivity is pretty well established. The weak link is that between price incentives and investments in the creation of knowledge and the adoption of new technology, and that is where we focus our attention in section 4.

3. A THREE-FACTOR VIEW OF AGRICULTURAL PRODUCTION

In this section, a simple three-factor framework for analyzing agricultural markets will be developed in order to explain the impacts of various changes on the "structure of agriculture" (the prices and quantities of inputs and outputs) and agricultural productivity. These changes include (a) exogenous changes in factor supplies to agriculture (e.g., increased urban demand for labour or cheaper producer goods or capital), (b) changes in consumer demand, (c) commodity policies of various types, (d) technological change, and (e) interactions among these (e.g., induced technological change). The idea is to have a consistent framework that can be used to consider the alternative sources structural change in agriculture, in order to assess their likely relative importance and different effects. An attempt will be made to connect the broad patterns of changes identified and described in section 2 to economic theory using this analytical framework.

First, Muth's two-factor model will be presented and summarized to illustrate the types of economic events that contribute to changes in factor productivities. Then we will proceed to consider a heuristic three-factor model so that we can analyze the differential impacts of exogenous events on prices, quantities and incomes to land, farmer-family labour, and other inputs. The two-factor case is relatively straightforward to discuss whereas, in the Muth-model setting, the three-factor case can be quite complicated and there is a loss of transparency and clarity unless restrictive assumptions are imposed.[4] To consider the three-factor setting, we use a heuristic model, without the formal algebra, of supply and demand for output and for three factors of production, with the markets connected to one another (as in the Muth model) by the technology of production and a market-cleating rule of competitive factor and product pricing. We use graphs to illustrate the sources of the past structural changes, described above.

[4] This issue is discussed by Alston (1991) and he illustrates the point using Holloway's (1989) article as an example. Two alternative ways to handle a three-factor case and preserve some transparency are (a) to use the Muth-model (logarithmic differential) approach, retaining a general view of the technology, but with some extreme assumptions about elasticities used to simplify the solutions, or (b) to use a restrictive assumption about technology (e.g., the Cobb-Douglas functional form, as was assumed by Helmberger 1991) instead to simplify the problem.

3.1 Muth's Two-Factor Model

Following Muth (1964) we can model the market equilibrium of a competitive industry producing a homogeneous product (Q) using two factors of production (X_1 and X_2) in terms of the following six equations:[5]

$$EQ = -\eta(EP + \tau_Q)$$

$$EQ = s_1 EX_1 + s_2 EX_2 + \delta$$

$$EW_1 = EP - \frac{s_2}{\sigma}EX_1 + \frac{s_2}{\sigma}EX_2 - \delta + \gamma$$

$$EW_2 = EP + \frac{s_1}{\sigma}EX_1 - \frac{s_1}{\sigma}EX_2 + \delta - \frac{s_1}{s_2}\gamma$$

$$EX_1 = \epsilon_1(EW_1 - \tau_1)$$

$$EX_2 = \epsilon_2(EW_2 - \tau_2)$$

where E denotes relative changes (i.e. Ey = dy/y = d(lny)), η is the absolute value of the elasticity of demand for the product, s_i is the cost share of factor i ($s_i = W_iX_i/PQ$) and $s_1 + s_2 = 1$, σ is the elasticity of substitution, δ is a neutral technical change and γ is a biased (X_2-saving) technical change. Muth (1964) included general shifters of output demand and factor supply which are represented here as shifts in the price direction by τ_Q, τ_1, and τ_2, respectively.

The endogenous variables in the model are industry output (Q), the amounts of the two factors used by the industry (X_1 and X_2), the producer price per unit of the final product(P), and the factor prices (W_1 and W_2). The first equation is the demand schedule for the industry's output, the second equation is a zero profit condition reflecting a constant returns to scale industry production function, the third and fourth equations are derived factor demand equations, and the fifth and sixth equations are the factor supply equations. Solutions for the relative changes in the endogenous prices and quantities-as functions of the exogenous shifters (here, subsidies and technical changes) and the parameters-are summarized in table 3.1. Figure 3.1 represents the model schematically.

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[5]This type of model generalizes previous work by Floyd (1965) and Wallace (1962) and is essentially identical in structure to the model used by Gardner (1975) to analyze changes in marketing margins. The same type of model has had extensive application in other contexts (e.g., see Gardner 1987).

Table 3.1: Solutions to the Equilibrium Displacement Model

Output and Input, Quantities and Prices

$$EQ = \frac{\eta[\epsilon_1\epsilon_2 + \sigma(s_1\epsilon_1 + s_2\epsilon_2)]\tau_Q \;+\; s_1\epsilon_1\eta(\sigma+\epsilon_2)\tau_1 \;+\; s_2\epsilon_2\eta(\sigma+\epsilon_1)\tau_2 \;+\; \eta[\sigma(1+s_1\epsilon_1+s_2\epsilon_2)+\epsilon_1\epsilon_2+s_1\epsilon_2+s_2\epsilon_1]\delta \;+\; s_1\sigma\eta(\epsilon_1-\epsilon_2)\gamma}{D}$$

$$EP = \frac{\eta(\sigma+s_2\epsilon_1+s_1\epsilon_2)\tau_Q \;-\; s_1\epsilon_1(\sigma+\epsilon_2)\tau_1 \;-\; s_2\epsilon_2(\sigma+\epsilon_2)\tau_2 \;-\; [\sigma(1+s_1\epsilon_1+s_2\epsilon_2)+\epsilon_1\epsilon_2+s_1\epsilon_2+s_2\epsilon_1]\delta \;-\; s_1\sigma(\epsilon_1-\epsilon_2)\gamma}{D}$$

$$EX_1 = \frac{\eta\epsilon_1(\sigma+\epsilon_2)\tau_Q \;+\; [(s_2\sigma+s_1\eta)\epsilon_2+\eta\sigma]\epsilon_1\tau_1 \;-\; s_2(\sigma-\eta)\epsilon_1\epsilon_2\tau_2 \;-\; \epsilon_1(\epsilon_2+\sigma)(1-\eta)\delta \;+\; \epsilon_1\sigma(\epsilon_2+\eta)\gamma}{D}$$

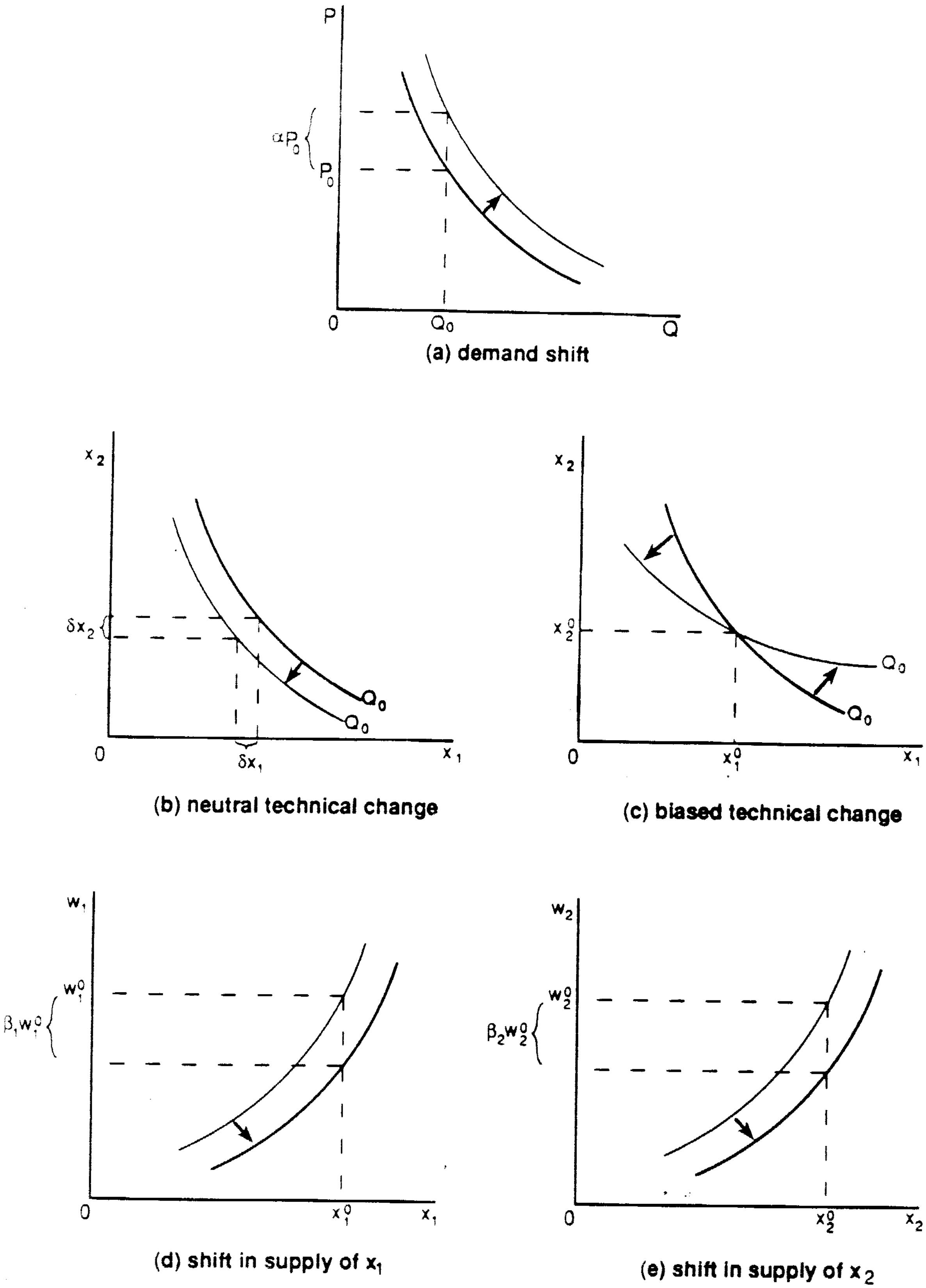
$$EX_2 = \frac{\eta\epsilon_2(\sigma+\epsilon_1)\tau_Q \;+\; [(s_1\sigma+s_2\eta)\epsilon_1+\eta\sigma]\epsilon_2\tau_2 \;-\; s_1(\sigma-\eta)\epsilon_1\epsilon_2\tau_1 \;-\; \epsilon_2(\epsilon_1+\sigma)(1-\eta)\delta \;-\; (s_1/s_2)\epsilon_2\sigma(\epsilon_1+\eta)\gamma}{D}$$

$$EW_1 = \frac{\eta(\sigma+\epsilon_2)\tau_Q \;-\; (s_1\sigma+s_2\eta+\epsilon_2)\epsilon_1\tau_1 \;-\; s_2(\sigma-\eta)\epsilon_2\tau_2 \;-\; (\epsilon_2+\sigma)(1-\eta)\delta \;+\; \sigma(\epsilon_2+\eta)\gamma}{D}$$

$$EW_2 = \frac{\eta(\sigma+\epsilon_1)\tau_Q \;-\; (s_2\sigma+s_1\eta+\epsilon_1)\epsilon_2\tau_2 \;-\; s_1(\sigma-\eta)\epsilon_1\tau_1 \;-\; (\epsilon_1+\sigma)(1-\eta)\delta \;-\; (s_1/s_2)\sigma(\epsilon_1+\eta)\gamma}{D}$$

where $D = \sigma(s_1\epsilon_1 + s_2\epsilon_2 + \eta) + \eta(s_2\epsilon_1 + s_1\epsilon_2) + \epsilon_1\epsilon_2 > 0.$

Figure 3.1: *The Muth equilibrium Displacement Model*



Changes in Prices and Quantities of Inputs and Outputs

As can be seen in figure 3.1 or in the equations in table 3.1, changes in quantities and prices of either of the inputs, or the output, may be induced by shifts in final demand or factor supply or by biased or neutral technical change. The qualitative impact of a particular exogenous shifter (e.g., a demand increase) on quantity or price of a particular input or output might depend on the magnitudes of the parameters characterizing supply and demand and technology; the quantitative impacts surely depend on all of those parameters. Using this model we can see how, and to what extent, the different primary causes of structural change in agriculture, could account for the gross changes we have witnessed.

Partial Factor Productivities

A simple transformation of the results in table 3.1 leads to an equation for the relative change in partial factor productivity of factor X_1 (say land)-the relative change in output per unit of input-as a function of the different types of subsidy or technical change:

$$E\left(\frac{Q}{X_1}\right) = EQ - EX_1 = \frac{\sigma[s_2(\epsilon_2-\epsilon_1)+\epsilon_1(1-\eta)]}{D}\tau_Q - \frac{s_2\epsilon_1\sigma(\eta+\epsilon_2)}{D}\tau_1 + \frac{s_2\epsilon_2\sigma(\eta+\epsilon_1)}{D}\tau_2$$

$$+ \frac{\eta[s_2\sigma(\epsilon_2-\epsilon_1)+\sigma+s_1\epsilon_2+s_2\epsilon_1]+\epsilon_1(\sigma+\epsilon_2)}{D}\delta - \frac{\sigma[\epsilon_1\epsilon_2+(s_2\epsilon_1+s_1\epsilon_2)\eta]}{D}Y$$

where $D = \sigma(s_1\epsilon_1 + s_2\epsilon_2 + \eta) + \eta(s_2\epsilon_1 + s_1\epsilon_2) + \epsilon_1\epsilon_2 > 0.$

All of the parameters in this equation are positive numbers. Each element can be used to deduce the sign of the effect of the exogenous shift of interest on the productivity of land.[6] The first element represents the effect of an increase in final demand (τ_Q). The effect is ambiguous depending on the values of elasticities. When land is relatively inelastically supplied $(\epsilon_2 > \epsilon_1)$, and demand for the product is inelastic $(\eta < 1)$, the expression is unambiguously positive: growth in final demand will increase the productivity of land. Under these conditions-everything else equal-one might expect countries that tax agriculture to have lower land productivity than countries that subsidize agriculture. The second element represents the

[6]The choice of X_1 representing land was arbitrary. This formula could be used to discuss partial productivity of either of the inputs used in the two-factor model with appropriate reinterpretation of parameters.

effects of increases in supply of land to agriculture (τ_1) that unambigously leads to a decrease in land productivity (conversely, then, a tax on land will increase its productivity in agriculture). The third element represents the effects of an increase in supply of nonland inputs (τ_2) that unambiguously leads to an increase in land productivity. Thus, a rise in the price of nonland inputs (say due to higher nonfarm wages) leads to lower land productivity. The fourth element represents the effects of a neutral technical change (δ) which unambiguously increases land productivity when land is relatively inelastically supplied ($\epsilon_2 > \epsilon_1$). Finally, as can be seen in the fifth element, a biased (nonland inputs saving) technical change (γ) leads to a reduction in productivity of land. Thus, a number of factors may have contributed to the general growth in the land productivity, including neutral technological change, land-using (labour-saving) biased technological change, increased demand for agricultural products, and higher nonfarm wages.

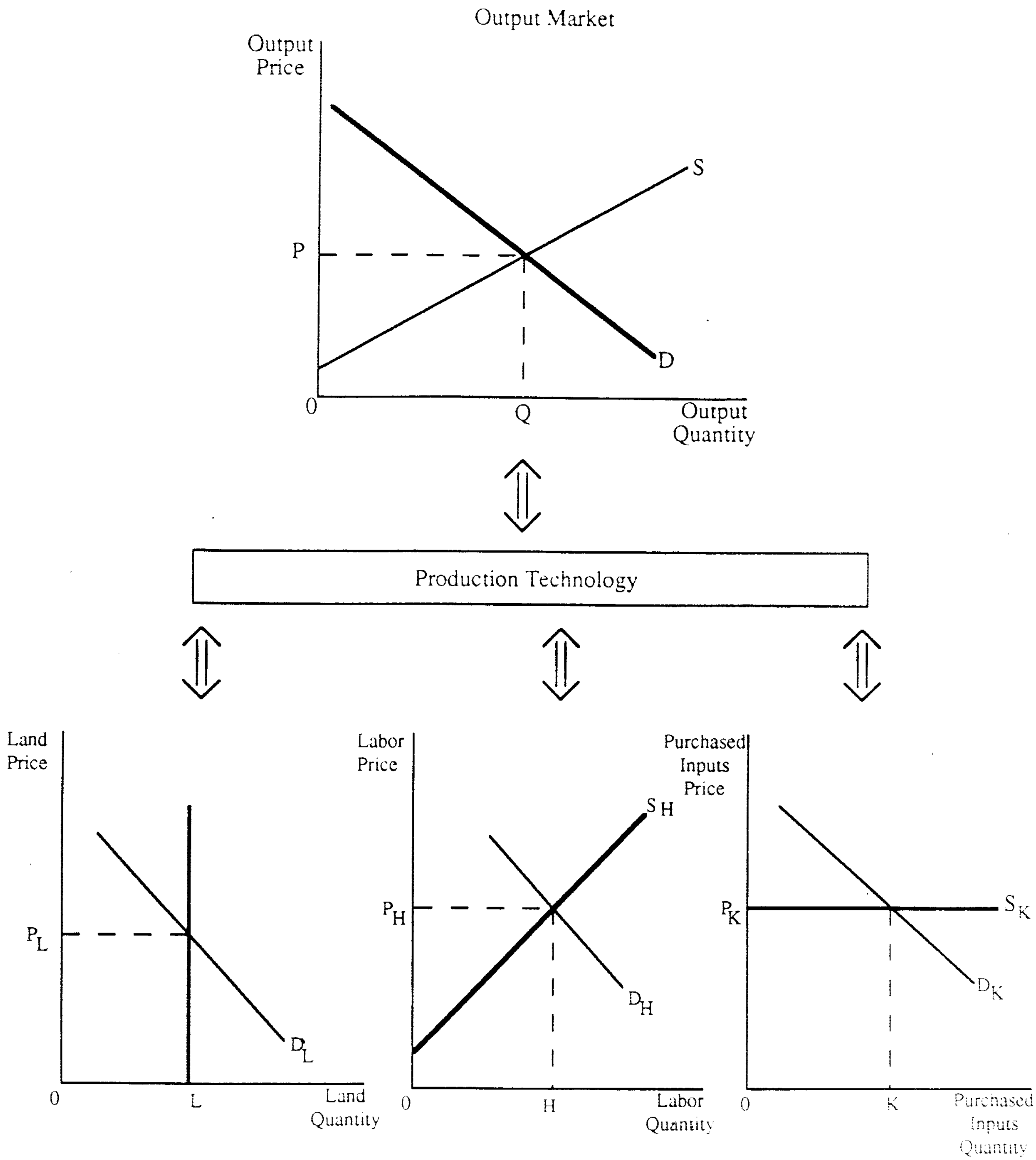
3.2 A Heuristic Three-Factor Model

Now we develop a three-factor model to consider, under plausible assumptions about the nature of markets and technology, what are the more likely explanations for the stylized facts presented in section 2. In this model, agricultural production is assumed to use three factors—land, which has a perfectly inelastic supply curve; purchased inputs, characterized by perfectly elastic supply; and family farm labour, with an upward-sloping supply curve.[7] Figure 3.2 shows this simple representation of the agricultural sector.

Using this model we can analyse the separate effects of the major trends that have affected the structure of agriculture: (a) rising nonfarm wages, (b) rising demand for agricultural output, (c) falling prices of purchased inputs (e.g., energy, chemicals, hired labour), and (d) neutral and biased (labour-saving) technological change. In this fashion we can identify the likely direction of the impact of each of these major trends on both the product market and the factor markets. In addition, we can put the set of trends together in an attempt to disentangle the components of structural change and their causes. This is done using diagrams similar to figure 3.2 to show the multimarket impacts of the different types of exogenous shifts.

[7]These assumptions follow Helmberger (1991). It is assumed that hired labour can be treated as a component of purchased inputs, in perfectly elastic supply to agriculture.

Figure 3.2: *A Three Factor Model of Equilibrium in the Factor and Product Markets*



Major Trends in Input and Output Quantities and Prices

Figures 3.3 and 3.4 illustrate the major long-term trends in prices and quantities of inputs and outputs characterizing U.S. agriculture. The most notable trends are the declining use of labour (associated with the rise in wages), the decline in the index of prices received by farmers relative to prices paid for inputs (especially labour), and the increase in output relative to inputs used (the only input that has grown significantly is capital). These general trends in U.S. agriculture are approximately duplicated in other OECD countries (e.g., see Bouchet, Orden and Norton 1989 for details on French agriculture, and Butault *et al.* 1992 for an EC-U.S. comparison).

Growth in Final Demand

An increasing population and increases in per capita incomes both have led to increases in the demand for agricultural output. Figure 3.5 shows the likely effects in the market for the final product and the three input markets when final demand increases. The result is an increase in output quantity and price, and a rightwards shift in demand for each of the three factors of production (we rule out by assumption the possibility that any of the factors of production is an inferior input), leading to an increase in land rent (but no change in land quantity), an increase in the quantity of purchased inputs (but no change in their price), and an increase in both the quantity and price of farmer-family labour. Thus, rising demand for agricultural output cannot have caused the reduction in labour use that has been observed. The increase in demand can account for increases in land rents, the use of purchased inputs, and rising wages in the agricultural sector. However, labor use would rise, not fall, in such a model.

Demand-side changes (arising from growth in population, growth in income per capita, and growth in government support for agriculture) have certainly been present in most OECD countries, and they can account (at least in part) for several of the trends in the agricultural sector, but not all of them. Even if the aggregate technology were characterized by a high degree of substitutability between capital and labor, and/or nonhomotheticity, the expansion of output (and the concomitant increase in wages) should not lead to a *reduction* in labor demand. Also, the demand-side explanation cannot account for falling food prices-increases in demand lead to increases in price, not decreases. Thus, it is necessary to have at least one other underlying cause, to account for what has happened in agriculture.

Figure 3.3: *Indexes of Quantities of Output and Major Inputs in U.S. Agriculture, 1950-90*

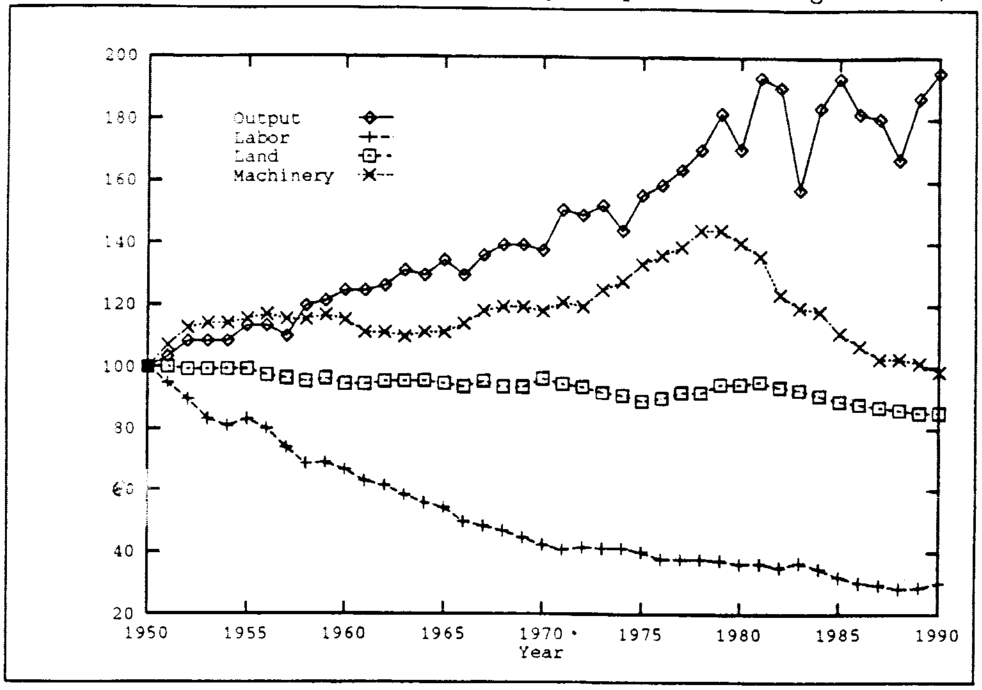
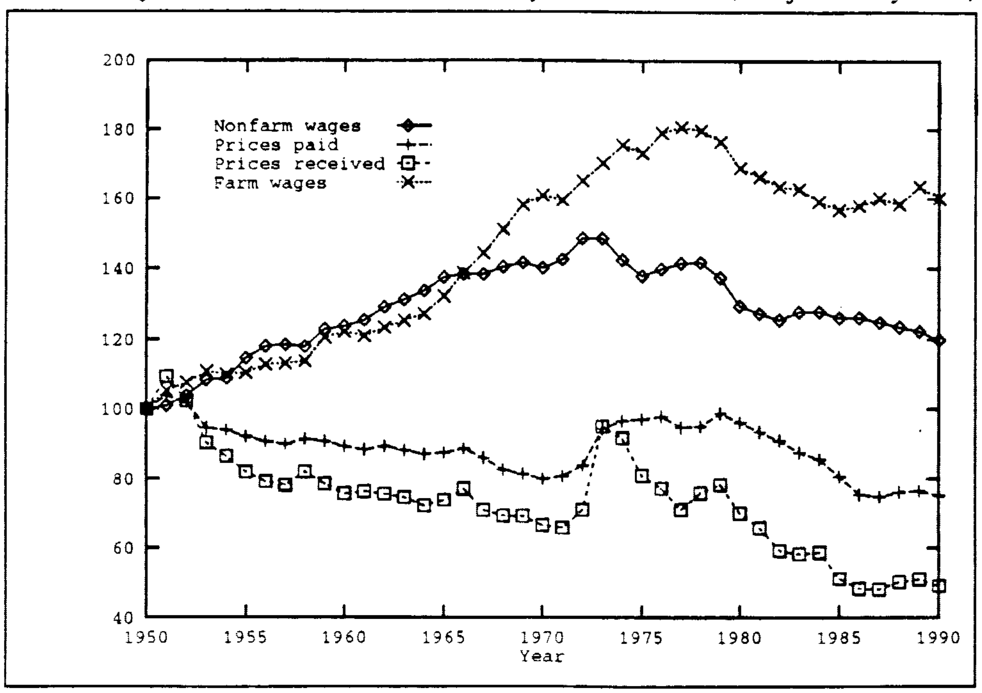


Figure 3.4: *Indexes of Prices Received and Paid by U.S. Farmers, Deflated by CPI, 1950-90.*



Source: *Economic Report of the President* (various issues). Washington D.C.: U.S. Government Printing Office. Definitions of data are available on request.

Figure 3.5: *Effects of Growth in Demand on Equilibrium in the Factor and Product Markets*

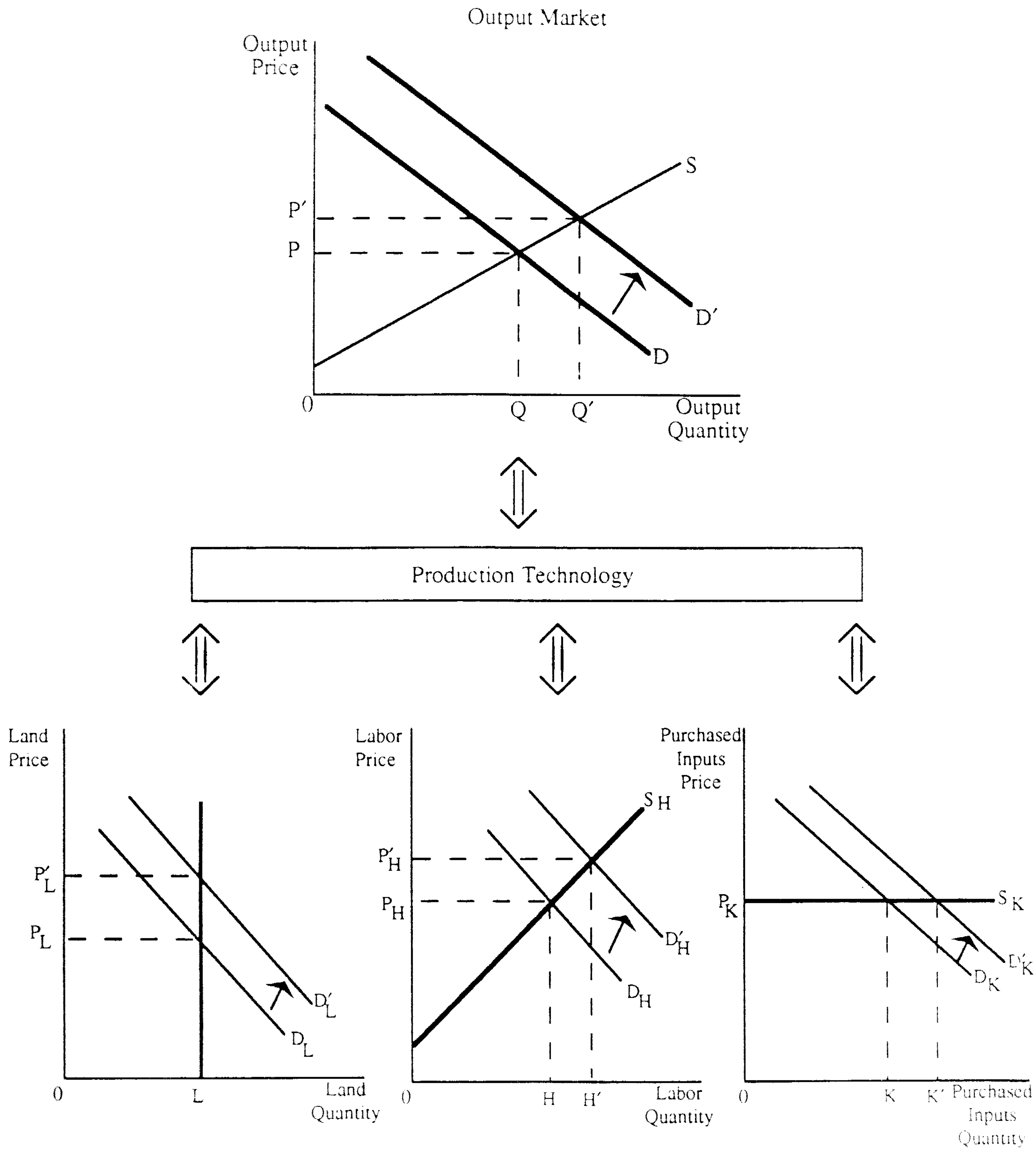
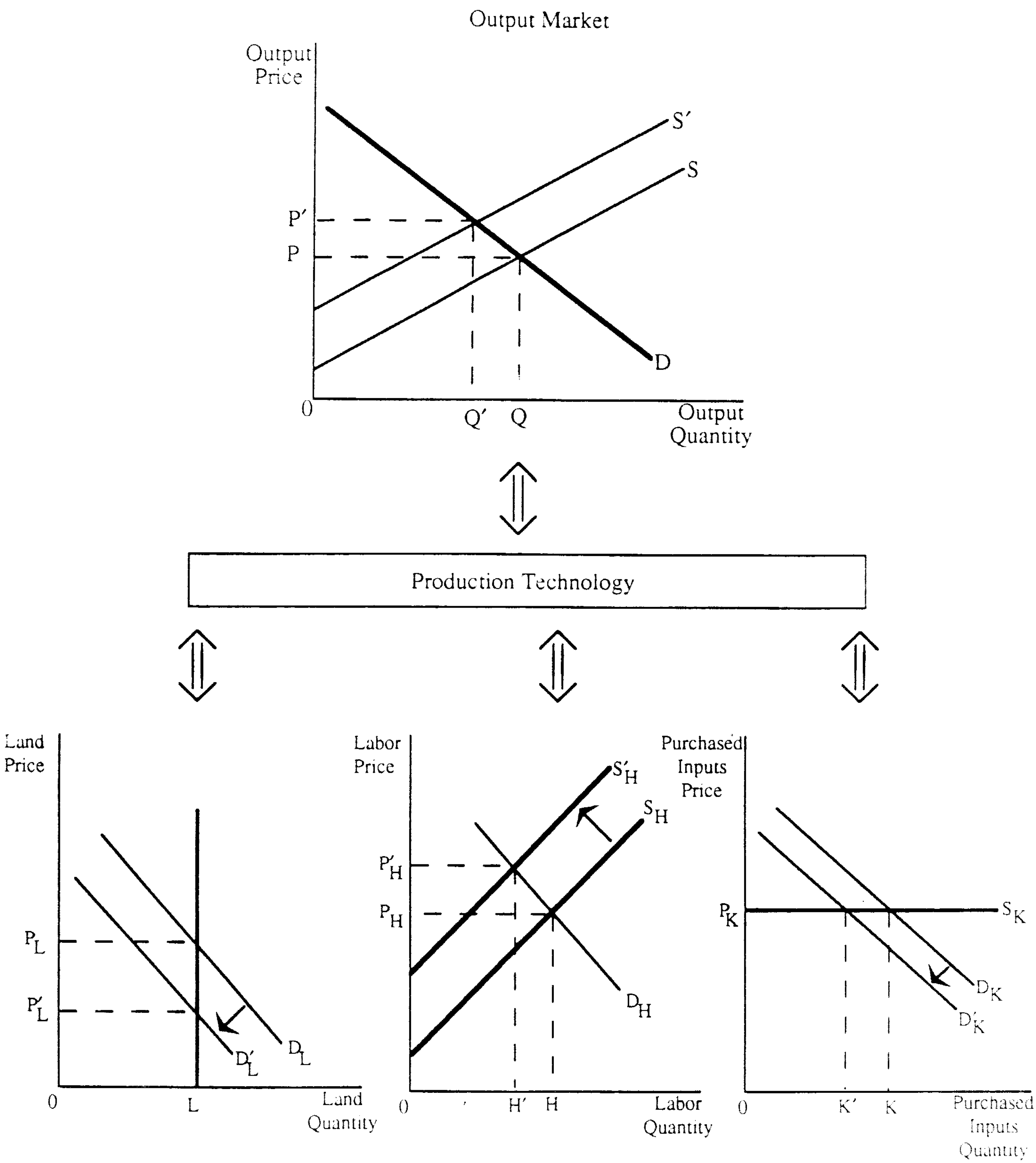


Figure 3.6. *Effects of Shifts in Labor Supply Equilibrium in the Factor and Product Markets*



Rising Nonfarm Wages

Nonfarm wages have risen substantially relative to both prices received by farmers and prices of other inputs during the postwar ***era (e.g.,*** figure 3.5). What are the structural implications of a rising wage? As Helmberger (1991) and many others have noted, the upward trend in nonfarm wages represents an increasing opportunity cost of remaining in farming. This higher opportunity cost necessitates an increased return to labor in the sector, and the labor supply curve representing the supply of labour to agriculture has shifted up, to the left, as a result. The effect of the increase in wages on demand for other factors of production depends on the relative sizes of scale and substitution effects (i.e., whether the partial elasticities of factor substitution are greater or less than the elasticities of demand for output). For most OECD countries, we would argue that aggregate demand for agricultural products is likely to have been elastic (in consideration of the role of international trade) while, at the level of aggregation of inputs being considered here, elasticities of substitution will be positive but substantially less than one. This leads us to an opposite conclusion from that suggested by Helmberger (1991) who had inelastic demand and an elasticity of substitution of one (implied by the Cobb-Douglas form). Rising nonfarm wages has led, most likely, to a reduction in the demand for land and purchased inputs.[8] This is shown in figure 3.6.

Thus, rising wages can account in part for adjustments in the labour market but not for the price and quantity changes that have been observed in the other factor markets or the output market. In the market for agricultural output, rising wages shows up as a shift of output supply to the left, leading to an increase in the price of agricultural output and a reduction in the quantity supplied-the opposite of the result that has been observed generally. Like the increase in demand, rising nonfarm wages cannot explain falling food prices.

Cheaper and Better Purchased Inputs

Figure 3.7 shows the impact of a falling effective price of purchased inputs (reflecting both lower prices of such inputs and improvements in their quality as embodied technical change).

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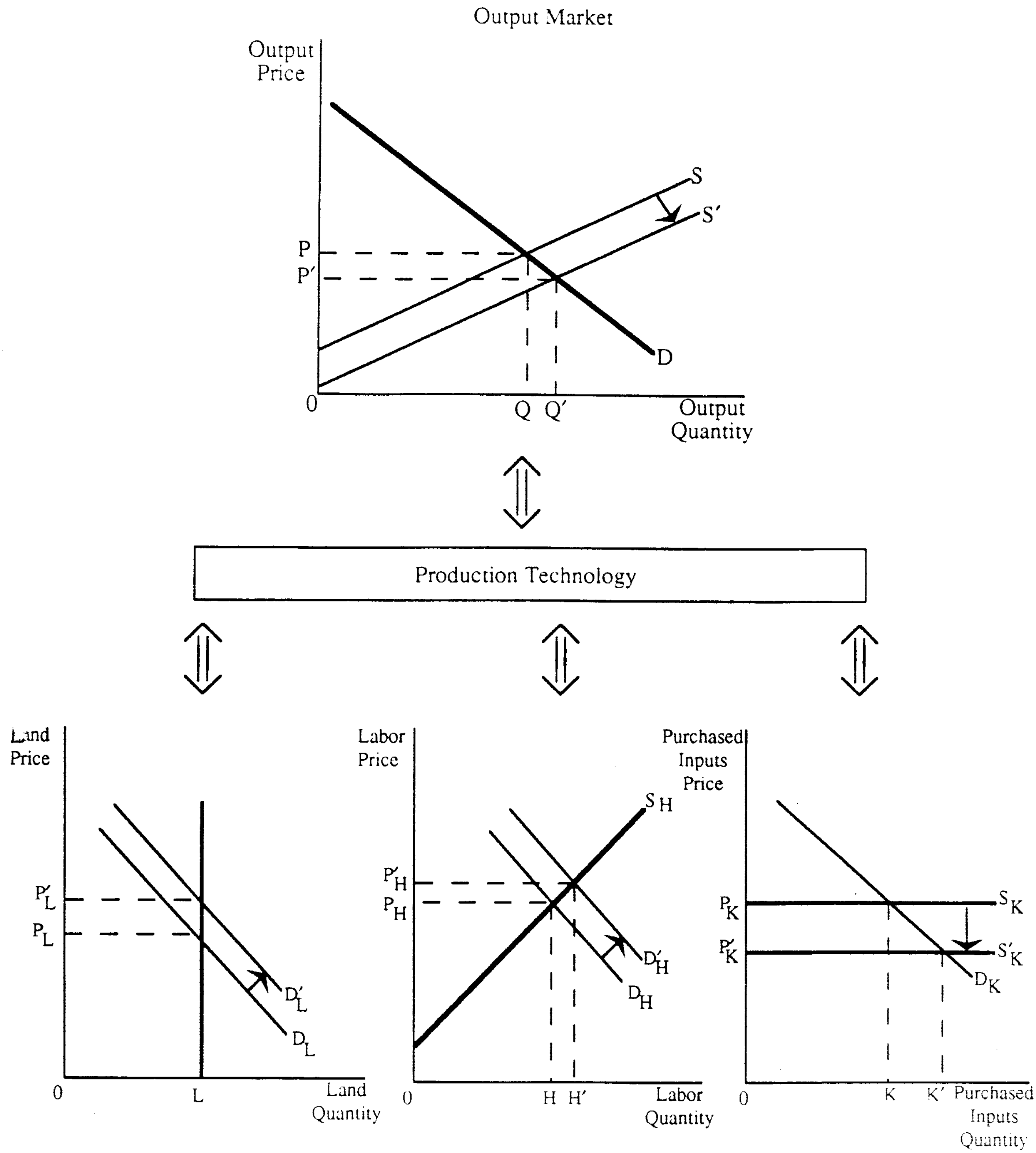
[8] This will be so at least in the short run. In the longer run, with induced innovation type responses, it is conceivable that the substitution effects become sufficiently large to swamp the scale effects, but this is a speculative argument at this stage.

Figure 3.7: *Effects of Cheaper Purchased Inputs on Equilibrium in the Factor and Product Markets*



The impact of a lower price of purchased inputs is, maintaining our assumptions from above, to increase use of purchased inputs and to increase demand for land and labour (and bid up their prices) and to increase supply of the final product (and reduce its price). All of these changes, except increased labour use, are in the directions indicated by the longer-term trends.

Combining Technical Change and other Factors

Neutral technical change can be represented in the output market by a rightward shift in the supply curve-consistent with a fall in the price of food and increased output. It also represents an increase in demand for each of the three factors of production (maintaining the view that the relevant demand is elastic). This is broadly consistent with the observed structural adjustment, except for the reduced labour use. However, much of the technical change that has taken place has been significantly factor biased (e.g., labor saving mechanizations). If such technical changes were sufficiently important relative to other changes, then technical change alone could explain everything except the rising wage rate. That is, it would lead to a rise in the demand for land and other inputs, a fall in demand for labour, an increase in supply of output, and a fall in the price of output. Such effects would be reinforced to the extent that the labour-saving innovations were *induced* by the rises in wage rates. The difficulty empirically is to distinguish between normal pure substitution responses (holding output and technology constant) and those that reflect induced technological change or of nonhomothetic output expansion effects.

The primary forces driving structural change in OECD agriculture would appear to have been the increased off-farm wage rate, drawing labour from agriculture and driving down the demand for other factors, and technical change, which may have reinforced the effects of higher wages in the labour market but which has more than offset those effects in the markets for land and purchased inputs and the output market. Output demand growth has probably been a relatively minor aspect, reinforcing the quantity effects in the market output and for land and purchased inputs.

3.3 Technological Change as a Component of Structural Change

We have stressed that central role of technological change in structural change in agriculture. Other events, especially nonfarm wage growth, have contributed in important ways to structural change. But the other major events cannot explain the major trend in food markets-rising output, and falling real prices. In addition, technological change is the only thing that can explain the enormous growth in total factor productivity that has occurred.[9] Thus, in order to understand the genesis of past changes in the structure of agriculture, and to appreciate the likely future path of structural change, and the implications of government policies for that, it is necessary to understand the technological changes and their causes.

What is the effect of government policy on the structure of agriculture? There have been few studies of this question. The discussion and modeling exercises above have illustrated some mechanisms for government policy, through factor or product markets, to influence the structure of agriculture in terms of the combinations of inputs used and the prices and quantities of outputs. However, the primary impact, given the central role of technological change, may be through R&D and through R&D policy and other policies to the extent that they affect incentives to adopt and innovate.[10] The next section, therefore, explores the impacts of commodity price policies on the development and adoption of new technology.

---

[9]Cheaper purchased inputs has contributed to lower food prices and greater output, too, but they cannot account for the phenomenal growth in total factor productivity.

[10]Some people think of the structure of agriculture in terms of the numbers of farm firms or farm families and measures such as the size distribution of farms. In many ways this is a more difficult subject than what we have been discussing so far; relatively little is known about the determinant of the size distribution of farms and how and why they change. In an important study, Sumner (1986) found no evidence to support the view that commodity policies have any important impacts on the structure of agriculture.

4. PRICE DISTORTING POLICIES, RESEARCH AND PRODUCTIVITY

4.1 Introduction-Views from the Literature

Technical change and productivity growth rates in agriculture differ markedly among countries, among industries within countries, and over time within industries and countries. Why this is so is not well understood. Although there has been ample speculation, there is little hard evidence. One candidate explanation is price policies. Influential economists have claimed repeatedly that prices-and therefore price distorting policies-affect productivity in important ways. For example, Schultz has argued that distortion of agricultural incentives has distorted the adoption of technology, the research agenda, and the value of agricultural research:

> "What appears not to be obvious is the critical allocative role that producer incentives play in attaining the optimum increases in productivity." (1978, p. 8)
>
> "The distortion of agricultural prices affects the adoption of the research output and this in turn affects the research agenda. Price distortion, therefore, tends to misguide agricultural research. Overvalued products receive unwarranted attention and all too few resources are allocated to research of the undervalued products." (1978, p. 14)
>
> "We have not allowed ourselves to see the effects that governmental policies have on the economic value of agricultural research." (1977, p.583)

The views of Shultz (1977, 1978) on this question appear to be shared by many economists, yet there is little formal evidence to support them.

Taking a broad view, price distortions (in either input markets or output markets) might affect productivity by affecting decisions about:

- total input use and input combinations for a given technology (i.e., factor use decisions),
- choice of technology from the existing set of technologies (i.e., adoption decisions),
- investments in R&D and new technology (i.e., research decisions).

These alternatives represent the same type of economizing responses over different lengths of run. In the short run, technology is given, but input choices may be affected in ways that affect productivity. In the intermediate length of run, incentives can influence the choice of production technology as well as input use for a given technology. Finally, in the longer run the set of technologies from which to choose is endogenous and can be affected by price distortions through their effects on the size and distribution of benefits from R&D and the incentives to invest in it. Alston and Pardey (1993) discussed each of these three components in detail.

The latter two topics (adoption decisions and research decisions) are components of the *induced innovation* idea of Hicks (1932)-which is most closely associated with the work of Hayami and Ruttan (1970, 1971). Induced innovation has been the subject of a great many studies. Thirtle and Ruttan (1987) review much of this literature and conclude that:

> "The theory of induced innovation and the historical research conducted within the induced innovation perspective are consistent with the inference that when either factor-factor or factor-product price relationships have been distorted, either through market or non-market interventions, the innovative behavior of both public research institutions and private research and development organizations will be biased.
>
> The impact of bias in the allocation of research and development resources is particularly serious because of the long lag between the allocation of resources to research and the impact of the new technology generated by research and development on production. If rates of return on research were low, the cost of such distortions would also be low. But because the rates of return to research have been very high, the costs of distortion are also very high." (p. 132)

One can quibble with the strength of this conclusion given the nature of the evidence on which it is based. Further, a recent study by Olmstead and Rhode (1992) has attacked the very foundations of the induced innovation literature. They use state and regional data to reinvestigate the issues studied by Hayami and Ruttan (1970, 1971) and conclude (p. 101) that "...many of the fundamental lessons drawn from American history need to be reconsidered." Olmstead and Rhode (1992, p. 101) say that their "...findings weaken the claim of historical confirmation of the induced innovation hypothesis and suggest elements of a more comprehensive, albeit more complex, view of the American experience." In spite of this new evidence against Hyami and Ruttan's specific results, the *idea of indu*ced innovation remains reasonable and plausible.

The market signals of abundance and scarcity of factors of production are likely to govern to some extent the creation, as well as the adoption, of factor-biased technologies. Whether R&D investment decisions are made by firms in the private sector or by people in government employment, they ought to (and it is likely they do) take account of the relative scarcity of different factors of production and the current and likely future mix of production, among other things. There can be little doubt that relative factor prices (and abundance) have a significant influence over the choice of technology to use and the mix of products. That is, there seems to be ample evidence that incentives affect the ***demand*** for new technology. There is less in the way of evidence that factor prices affect the ***supply*** of new technology.

Binswanger (1974) solved an optimization problem in which research investments are chosen in order to maximize profits under a variety of conditions. Factor and product prices are exogenous in the analysis. Thirtle and Ruttan (1987, p. 32) summarize his main results as:

> " 1) Any rise in the expected present value of the cost of a factor will lead to an increased allocation of resources to research that saves that factor.
> 2) **A rise** in the cost of research that saves a particular factor or a decline in the productivity of that research will reduce the allocation to that line of research, and hence bias technical change in favor of that factor.
> 3) With no budget constraint on research activities, a rise in the value of output (due to greater output at a higher price) will increase the research budget and hence the rate of productivity growth. "

These results make intuitive sense for the private firm and perhaps the industry. They extend naturally to the national level as well. For instance, it would seem to make little sense for a country that has relatively abundant land and scarce capital to pursue land-saving (labour- or capital-using) technologies.

4.2 Effects of Price Distortions on Research Benefits

The overwhelming majority view in the literature would appear to be that government policies have contributed significantly to the international differences in productivity growth rates. Most would argue that taxation of agricultural production has acted directly and indirectly to depress agricultural productivity. In section 3 it was shown that the gross evidence from the data is not as strong as the views expressed by economists about the relationship between price distorting policies and agricultural productivity and its determinants. In the work that follows we focus on the effects of price policies on the size and distribution of the benefits from R&D, and therefore on the incentives of various groups to invest in agricultural research as a basis for drawing implications for distortions in the total size and the pattern of private- and public-sector investments in agricultural R&D.

Alston, Edwards and Freebairn (1988) analyzed the qualitative effects of a range of price distorting policies on the size and distribution of research benefits under a range of market scenarios. They considered a variety of market conditions (closed economy, large or small country exporter or importer) and, in some cases, different types of research-induced supply shifts. Their main findings (pp. 285-7) may be summarized as: (a) all of the forms of intervention studied modify the pattern of benefits relative to free trade; (b) world research benefits may be increased, reduced, or left unchanged, depending on the market circumstances and the form of intervention; and (c) a government intervention reduces (increases) total welfare gains from a research-induced supply shift by an amount equal to the increase (reduction) in the social costs of market intervention resulting from that same supply shift. Unfortunately there are not any more general rules about the implications of commodity market distortions for the size and distribution of research benefits. Thus, they concluded, it seems that each type of intervention in each market situation must be considered in a case-by-case fashion. Some subsequent work has expanded on the set of theoretical results and measured the quantitative importance of the issue.[11] Several other studies have adjusted measures of research benefits to incorporate the effects of price distorting policies.[12]

Several assumptions condition both the size and distribution of research benefits in the absence of policies and the impact of price policies on the size and distribution of benefits. These include assumptions about the functional forms of supply and demand, the nature of the research-induced supply shift, the trade status of the country, the instruments of protection, and elasticities of supply and demand.

Nature of Supply Shift and Producer Benefits

As shown by Duncan and Tisdell(1971), Scobie (1976), Lindner and Jarrett (1978), and others, whether producers gain from research depends on the nature of the research-induced supply shift and on the elasticity of demand. The two most popular alternative specifications are either (a)

[11] Examples include de Gorter and Norton (1988), Oehmke (1986). de Gorter, Nielson and Rausser (1992), Chambers and Lopez (1992), Murphy, Furtan and Schmitz (1992), Alston and Martin (1993a,b), Martin and Alston (1993).

[12] Examples include Haque, Fox and Brinkman (1987) and Zachariab, Fox and Brinkman (1989).

a pivotal shift of a constant elasticity supply function, or (b) a parallel shift of a linear supply function. In the latter case producers invariably benefit from the research-induced supply shift, In the former case, producers gain from a research-induced supply shift when demand is elastic; they lose when demand is inelastic.

In most cases there are grounds for assuming that the relevant demand is elastic (in most cases the products are traded, or potentially tradeable, internationally, and few countries have significant market power in any products over the length of run that is pertinent for measuring research benefits). That would be sufficient to ensure benefits to producers from a pivotal shift.[13] In addition, even in the exceptional cases when it is reasonable to assume inelastic demand, it is reasonable to assume that the nature of the supply shift will be such that producers will benefit from research. As argued by Rose (1980):

> "For most innovations, the best information available may be a cost-reduction estimate for a single point on the supply curve. For the reasons outlined above, it is unlikely that any knowledge of the supply curve, or the position at which the single estimate applies, will be available. The only realistic strategy is to assume that the supply shift is parallel." (p. 837)

Policy Instruments and Trade Status

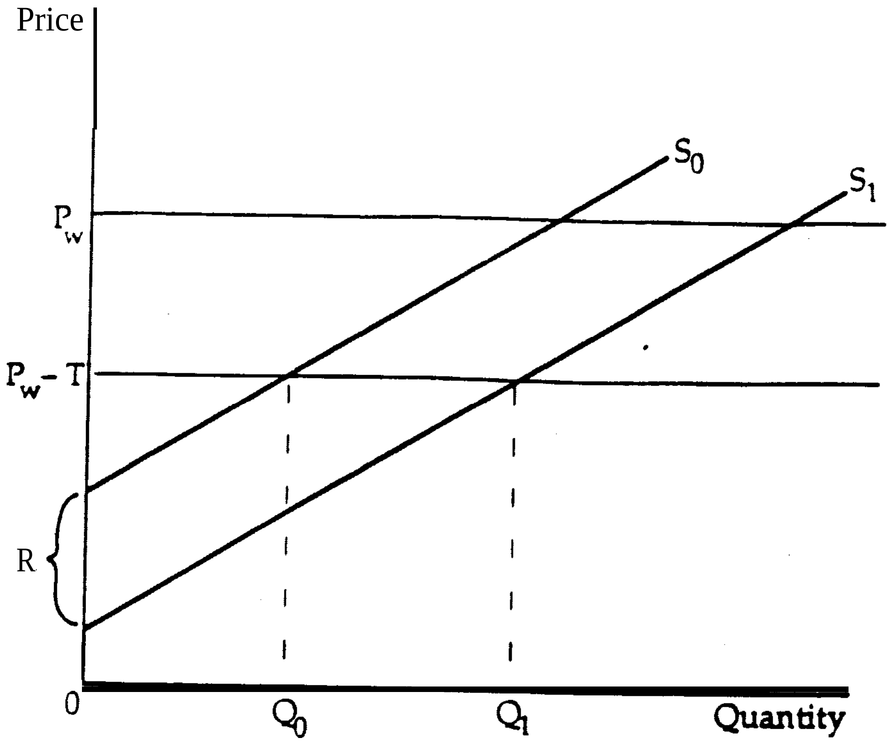
The assumption that producers always gain (or, at least, do not lose) from agricultural research is difficult to refute, unless there are policies in place that eliminate producer benefits.[14] Whether consumers benefit from research is more clearly dependent on market circumstances. Roth producer and consumer research benefits also depend on trade status and the effects of protection on the size and distribution of benefits may depend on the policy instruments. The small country case, with an export tax, is shown in figure 4.1.[15]

[13] Gardner (1988) provides a formal proof. To ensure benefits to producers regardless of the type of shift requires perfectly elastic demand.

[14] When supply is perfectly elastic there will be no producer gains, even with parallel supply shifts.

[15] The model can also be reinterpreted to represent an export subsidy and the case of a small country importer is closely analogous. The small country case is relatively general to the extent that most countries are *potentially* small countries in trade in the main commodities in the intermediate- to long-run (i.e., the closed economy case is often a result of trade barriers).

Figure 4.1: Research Benefits in a Small Country with an Eport Tax



In figure 4.1, a research-induced supply shift (from S_0 to S_1) has no effect on the price paid by consumers or the price received by producers in this case. There are no consumer research benefits in the small country case, whether or not the market is distorted at the border. Assuming a parallel research-induced supply shift, producer benefits are approximately equal to the cost saving per unit (R) multiplied by the pre-research quantity (benefits from a pivotal supply shift would be about half as much). The price distortion affects producer benefits by affecting the quantity on which benefits are obtained. With a tax (*T* per unit), that quantity is lower and so are research benefits; with a subsidy, quantity is greater and so are research benefits. However, the research-induced supply shift also affects government revenues: with a tax they are increased, with a subsidy they are reduced. Indeed, as shown by Alston, Edwards and Freebaim (1988), in this case, the amount of the increase in government tax revenue due to research is equal to the amount of reduction of producer research benefits due to the tax. Thus, total research benefits are unaffected by the presence of a tax or subsidy. Only the distribution is affected.[16] This general result also applies in the case of a closed economy: the total research benefit is unaffected by a tax but the distribution of benefits among producers, consumers, and government revenues is affected.

In an intermediate case, where both supply and demand have some slope so that both producers and consumers benefit from research in the absence of market distorting policies, price policies and research policies may work in the same direction or the opposite directions, depending on whose welfare is being considered. For instance, an output subsidy and taxpayer funded research are alternative means of achieving an increase in producer and consumer welfare at the expense of taxpayers and a combination of the two policy instruments may be more efficient than either alone. With such a policy, ***producer*** incentives to fund research are greater in the presence of positive protection and less in the presence of negative protection.

[16] A potentially important qualification to these results follows when the marginal opportunity cost of government funds is greater than one for one, so that government spending does not correspond to taxpayer welfare. When government revenues are worth $(1+\phi)$ dollars of taxpayer surplus per dollar, total research benefits are greater in the presence of a tax policy -- where research leads to a rise in government revenues (AG) that is worth $(1+\phi)\Delta G$ to taxpayers, which is greater than the corresponding AG reduction in producer research benefits due to the tax. By the same arguments total research benefits are ***less in*** the presence of an output subsidy. See, for example, Alston and Mullen (1992), Alston and Hurd (1989), Fox (1985), Dalrymple (1990).

Table 4.1: Qualitative Effects of Price Distorting Policies on Welfare and on Research Benefits Among Groups

Policy/ Trade Status	Effects of Policy on Welfare of:			Effects of Policy on Research Benefits to:			
	Producers	Consumers	Taxpayers	Producers	Consumers	Taxpayers	Total
<u>Output Tax</u>							
Nontraded	-	-	+	-	-	+	0
Small Exporter	-	0	+	-	0	+	0
Small Importer	-	0	+	-	0	+	0
<u>Export Tax</u>							
Small Exporter	-	+	+	-	0	+	0
<u>Import Subsidy</u>							
Small Importer	-	+	-	-	0	+	0

Notes: In this table "+" denotes that a policy increases welfare or increases research benefits, "-" denotes that the policy reduces welfare or reduces research benefits, and "0" denotes that a policy has no effect on welfare or research benefits.

The entries for an output subsidy would be opposite in sign for those of an output tax. Entries for an export subsidy would be oppsoite those for an export tax and entries for an import tariff would be opposite those for an import subsidy.

Some other cases are less clear-cut than the case of an output subsidy or tax or a trade subsidy or tax by a small country. For instance, in a large country an export tax disadvantages producers and benefits consumers and taxpayers, an import tariff benefits producers and taxpayers and disadvantages consumers, while agricultural research benefits producers and (perhaps) consumers and disdvantages taxpayers. In these cases research and price policies may or may not be complementary means of raising welfare of particular interest groups.

Representative Results for Particular Policy Scenarios

Table 4.1 shows the effects of various tax or subsidy policies, in a closed economy or a small open economy, on (a) the welfare of producers, consumers, and taxpayers and net welfare, and (b) research benefits to producers, consumers, and taxpayers and total research benefits. The analysis underlying the entries in table 4.1 follows that of Alston, Edwards and Freebairn (1988) and the basic results are the same as theirs. Two measures of total benefits are shown. The first ($\phi = 0$) is the conventional measure where taxpayer welfare is measured by changes in government revenues while the second allows for the deadweight cost of taxation to fund government spending ($\phi > 0$).

Negative protection to producers typically will mean a smaller volume of output and smaller producer research benefits. Thus negative protection to producers tends to reduce their incentives to carry out research, to fund it, and to lobby for it. By the same token, negative protection to consumers will tend to decrease consumer research benefits and discourage them from supporting investments in agricultural research. Policies that confer positive protection on consumers (i.e., lower consumer prices) will tend to increase consumer research benefits. Thus the effects of negative producer protection on *consumer incentives* will depend on whether the incidence on consumers is positive or negative. Negative protection to producers might lead to smaller consumer research benefits (as in the case of a nontraded good with an output tax, negative consumer protection), larger consumer research benefits (as in the case of a traded good with export controls, positive consumer protection), or no effect on consumer research benefits (e.g., an export tax in a small country).

From the point of view of government revenues (or taxpayer welfare), the direct effect of public-sector research is negative. Indirect effects arise through the effects of research-induced supply shifts on the budget costs of commodity policies. Where goods are taxed explicitly, either in production or in trade, government revenues rise when research leads to an increase in production (an increase in the tax base). In all of the cases considered in table 4.1, negative producer protection ***increases*** taxpayer benefits from research either by increasing tax revenues or reducing subsidy expenditures; positive producer protection ***reduces*** taxpayer research benefits. That is, the effect of each policy on taxpayer research benefits is opposite to the effect on producer research benefits."

4.3 General Equilibrium Approaches

The models in the work discussed so far have been all comparative static, partial equilibrium models. They have all applied at a single market level (i.e., they have not dealt with distribution of research benefits throughout the marketing chain for agricultural products), and they have dealt with single commodities in isolation, ignoring the interplay between related commodity markets. In addition, they have all used Marshallian consumer and producer surplus as a measure of research benefits.[17]

A number of recent studies have used a multimarket approach to study research benefits in a disaggregated setting (e.g., Mullen, Alston, and Wohlgenant 1989). This literature was reviewed by Alston (1991) who also attempted to extend the set of results into a *distorted* multimarket setting, but the outcome was disappointing. It proved impossible to obtain meaningful measures of the total research benefit and its distribution in a supply and demand model with more than one source of general equilibrium feedback (Thurman 1991a, 1991b). Subsequent work has shown that it is possible, however, to solve those problems using an explicit general equilibrium approach (e.g., Martin and Alston 1993).

Single-market Models

When a system of supply and demand equations is used to measure the price and quantity changes caused by a supply shift in one market, those measured responses will reflect feedback

[17] Alston Edwards and Freebairn (1988, p. 286) considered a range of other policies and, while there is some ambiguity in the large country cases and for some policies, the general tendency was for effects of price policies on producer research benefits to be opposite the effects on taxpayer research benefits.

from related markets. In such a setting, a single market model can measure the full welfare effects. Just, Hueth and Schmitz (1982, p. 192) put it succinctly: "...net social welfare effects over the economy as a whole of intervention in any single market can be measured completely in that market using equilibrium supply and demand curves of sufficient generality."

However, a full general equilibrum treatment of supply and demand is necessary (implicitly) for those measured effects to be valid. Further, an explicit general equilibrium treatment, reflecting the complete set of underlying supply and demand curves is required if measures are to be obtained of the distribution of benefits. This last point was made by Thurman (1991a, 1991b) who pointed out that the areas behind the general equilibrium supply and demand curves for a commodity may have no welfare significance taken separately (in that they may not measure welfare of an identifiable group) although they do taken together (as a measure of the total welfare change). As shown by Martin and Alston (1993), an explicit multimarket model can, however, yield meaningful measures of the size and distribution of benefits in a quite general setting.

Multimarket Models

Martin and Alston (1993) advocate using a distorted ***Balance of Trade Function*** approach, exploiting recent developments in the modem, dual, approach to the welfare economics of trade in general equilibrium. In this type of approach, the linkages between supply and demand for a particular good, and the full general equilibrium for all goods, are explicit and transparent. This arises because the derivatives of the consumer expenditure function and the producer profit function that are involved in the general equilibrium model can be interpreted as supply and demand curves corresponding to those in the partial equilibrium model. Martin and Alston (1993) distinguish between the behavioural model (the system of supply and demand equations and market clearing conditions, with *endogenous* prices and quantities) and the expenditure function for the welfare evaluation (with *exogenous* prices and other variables derived from the solutions to the behavioural model). The welfare measure shares structural parameters with the behavioural model but the welfare analysis need not involve explicitly taking integrals behind the supply and demand functions that comprise the behavioural model *per se.*

Martin and Alston (1993) have illustrated the use of a *Balance of Trade Function* to evaluate the welfare impacts of technological change. They have shown that this type of approach can be used to describe and measure the welfare impacts of a variety of types of technical change in a very general setting-including multiple market distortions and multiple sources of general equilibrium feedback. The money metric they define is a Hicksian measure and, if the supply and demand curves used to generate the prices and quantities are derived directly from the underlying preferences and technology, then the welfare measures will be exact. Their approach is practicable, as is demonstrated by an illustrative example in Martin and Alston (1993) and in a more comprehensive example using an application of the OECD-World Bank *RUNS* model by Alston and Martin (1993b). As well as being useful for practical welfare evaluation, the Martin-Alston approach can be used to derive general results on the implications of market distortions for benefits from new technology.

4.4 Popular Myths-Normative Perspectives

In the literature there is a well-established viewpoint that technological change is bad for farmers, even when it is good for the economy as a whole (one variant of this is the *treadmill hypothesis). There* **is also a converse view in the literature. Some** studies have suggested that due to the manner of funding arrangements that public sector agricultural R&D might be profitable for agriculture but unprofitable for the nation as **a** whole-i.e., the benefits may not justify the costs when they are calculated properly (e.g., Fox 1985; Dalrymple 1990). The main idea here is that studies have not allowed for the full social costs of government expenditures due to the deadweight costs of taxation (e.g., Fullerton 1991; Alston and Hurd 1989). Another potential source of underestimation of costs is when total benefits are attributed to public-sector R&D, ignoring the contribution of private-sector R&D.

More recently, several studies have proposed an even more negative view of agricultural research-that it involves a negative gross return (e.g., Murphy, Furtan, and Schmitz 1992; Chambers and Lopez 1992). This latter idea connects closely to the literature on market distortions and research benefits and is of direct interest here. However, the other ideas are sufficiently pervasive and important that it is worth pointing out here that there is no empirical evidence anywhere to support the view that technological change in agriculture results in a loss of producer surplus to farmers, nor that it results in a net loss to the nation as a whole, nor that it is immiserizing in the sense of producing a negative gross return. On the contrary, available evidence supports the view (a) that agricultural research generates a handsome gross and net return to the public-sector investments, and (b) that farmers benefit along with consumers.

Research and Technological Change are Bad for Agriculture ?

Many economists assume that producers lose as a consequence of agricultural research. A recent example is provided by de Gorter, Nielson, and Rausser (1992) who provide analytic results to show a general condition under which producers benefit or lose from changes in research expenditure. As shown by Alston and Pardey their result is equivalent to showing that producers lose when the research-induced supply shift is divergent and demand is inelastic. However, Gardner (1988) concludes:

> "Discussion of the international context and alternative supply specifications suggest that the more likely case for typical agricultural commodities is that producers will gain from research, although a great deal of information especially on the supply side is necessary to make a judgement in a particular case." (p. 26)

The notion that research is bad for agriculture can be traced to some specific modeling assumptions that cannot be justified for most situations. As discussed above, when a supply function pivots out against an inelastic demand, producer surplus will fall. The inelastic demand is sufficient to mean that an increase in supply leads to a fall in gross revenue. In order for that to mean a fall in net revenue as well, costs must fall by less than revenue does, and that result is guaranteed by the assumption of a pivotal shift. Of course, there is no theoretical or empirical basis for assuming that supply functions shift in a pivotal fashion. In any event, in most cases, the assumption of inelastic demand is obviously inappropriate. In some cases, the combination of technological change and market parameters could mean that producers lose from research; but such cases must be regarded as the exceptions rather than the norm.

Negative Returns to Research?

As discussed above, Alston, Edwards, and Freebairn (1988) found that protection reduced research benefits by an amount equal to the increase in cost of protection caused by the research-induced supply shift. This claim was supported by a number of examples, but it was not established as a general case. The general case is easily demonstrated, as shown by Alston and Martin (1993a), using the welfare measure proposed by Martin and Alston (1993).

Let H_A be the actual measure of total welfare in the economy (defined by the exogenous technology and the choice of price policy) and H_{MAX} be the maximum attainable total welfare in the economy, defined by the optimum price policy given the exogenous technology. Then we may define the social cost of distortion in the economy as $D = H_{MAX} - H_A$. Therefore, actual welfare may be partitioned into the maximum attainable welfare and the cost of distortion:

$$H_A = H_{MAX} - D$$

Thus, when technology changes, the change in welfare is equal to the change in potential welfare (i.e., the benefit in the absence of distortions) minus the change in the cost of distortions:

$$\frac{dH_A}{d\tau} = \frac{dH_{MAX}}{d\tau} - \frac{dD}{d\tau}.$$

This general result and the arguments surrounding it relate closely to the literature on immiserizing growth (including immiserizing technological change). Two recent studies (Murphy, Furtan, and Schmitz 1992; Chambers and Lopez 1992) suggested that agricultural R&D could have a negative gross benefit due to the presence of price-distorting policies. Alston and Martin (1993a) discussed the connection between those papers and the earlier work on immiserizing technological change by Johnson (1953, 1958, 1967), Bhagwati (1958, 1968) and Gruen (1961). Alston and Martin (1993a) proved that, as shown above, technological change could be immiserizing only if the policy and market situtation were such that the research-induced increase in social costs due to existing distortions were greater than the potential benefits from research. Situations where those conditions are met will be unusual.

Don't Do Research On Protected Commodities?

Another popular myth is that it is socially wasteful to do research on protected commodities. This myth seems to be supported by the results of Murphy, Furtan, and Schmitz (1992) and Chambers and Lopez (1992). It is often expressed in an intuitive form that reflects a misconception of the role of technological change and the nature of price distortions. For example, it may be expressed: "there's no point in doing research on commodity X because it is already in surplus and research will lead to greater productivity and will simply add to the existing surplus." What this argument neglects is that (a) it is the inframarginal cost savings, not just the marginal output increases, that determine whether research is profitable, even when the policy instrument means that there is excess production, and (b) many protective instruments do not involve excess production. As shown by Alston, Edwards and Freebairn (1988) the effects of price distortions on research benefits depend on many variables. In many cases the presence of a price distortion will affect only the distribution of benefits. In some cases, research will reduce the social costs of existing distortions and research benefits will be greater in the presence of a price-distorting policy than they would have been without it.

4.5 **Theoretical Effects of Price Distortions on Research Investments-Positive Economics**

Suppose research investments are a function of the size and distribution of expected research benefits. The results of Alston, Edwards, and Freebairn (1988) and others indicate that there may not be a consistent relationship between the size and distribution of research benefits and summary measures of market distortions (say a nominal protection coefficient or a producer subsidy equivalent). The magnitudes and directions of effects depend on the nature of the market and the protective instruments being used. This raises doubts about the possibility of finding a consistent reduced-form relationship between rates of protection and investment in agricultural R&D. Also, rates of protection may change passively when border prices change exogenously-due to changes in world prices or changes in exchange rates-and the changes in protection may be positively or negatively correlated with incentives to produce and carry out R&D. Thus, there may be further reasons (in addition to those identified by Alston, Edwards, and Freebairn 1988) why the correlation between investments in R&D and rates of protection is ambiguous. In addition, some argue that price policies are endogenous.

Endogenous Policy

Alston, Edwards, and Freebairn (1988), and most others, treated price distortions as exogenous to research decisions. Some recent literature has challenged this type of approach more generally and suggested that a formal model should be developed that is capable of explaining both price policies and research policies of governments in a political economy framework. For instance, Gardner (1988) models research and price policies as if a single government decision-maker chooses a combination of them to maximize a welfare trade-off among interest groups. Other studies have taken a similar approach (e.g., de Gorter, Nielson and Rausser .1992).

Alston and Pardey (1993) reviewed the approaches and concluded that it may be empirically reasonable-given the differences in timing of impacts of today's research and price policies (R&D impacts occur with long and variable lags), and given the typical bureaucratic separation of the decisions on price and R&D policies (e.g., in the United States, agricultural R&D expenditure changes are largely state-level decisions while price policies are federal)-to treat price policies as exogenous to R&D investments. Taking that view, one can analyze research policy taking price policies as given exogenously and draw meaningful conclusions about the implications of price policies for research investments, at least in the short run. Even with this simplification, it is not possible to infer a consistent relationship between government incentives to invest in research and a summary measure of price distortions (such as the nominal rate of protection). This arises primarily because the budget implications of protection vary among protective instruments, and budgetary implications are likely to be critical-even with equal welfare weights. These arguments mean that, in order to analyze the effects of price policies on research investments, it probably is important to consider differences among policy instruments in terms of their effects on the size and distribution of research benefits and costs.

Effects of Exogenous Policies on Public-Sector R&D

The effects of exogenous policies on government R&D incentives depend on the effects on the welfare of the different groups. In addition to the benefits from research, the government must consider the costs that are borne by taxpayers. And, as argued by Fox (1985)and Dalrymple (1990), there might be an excess burden of taxpayer welfare associated with the raising of revenue to fund agricultural research. In the case of equal welfare weights and no deadweight costs of taxation ($\phi=0$), none of the policies in table 4.1 changes the total benefits from research. However, when there are deadweight costs of taxation ($\phi > 0$), total research benefits are greater when production is taxed than under free trade. While this indirect effect (on the benefits side) would indicate that an increase in ϕ will imply greater incentives for research, the direct effect of greater values of ϕ on the costs of research will be in the opposite direction and is likely to be more important. Where positive rates of protection to - government favor producers over taxpayers and consumers, and the protection leads to an increase in producer research benetits, the net effect is likely to favor greater research.

Government funding of research depends on the relative importance of different groups. and the effects of price policy on research funding depend on their effects on the distribution of research benefits. The government's objective function is maximized by choosing a research investment (R) so that:

$$\frac{dW}{dR} = \theta\frac{dG_P}{dR} + \frac{dG_C}{dR} + (1+\phi)\frac{dG_T}{dR} = 0.$$

The components of this equation are interrelated. For example, when producer welfare is heavily weighted (i.e., $\theta > 1+\phi$), producers will receive positive price protection (say, a subsidy). This policy will increase producer research benefits and reduce taxpayer research benefits compared with a no-policy situation. Thus when $\theta > 1+\phi$, producer research benefits will be greater (since $\partial^2 G_P/\partial R\partial\theta > 0$ and $\partial^2 G_T/\partial R\partial\theta < 0$).

Because producer welfare is relatively heavily weighted, the price policy will most likely lead to a greater incentive of the government to invest in research.[18] Thus. positive pirce protection increases the incentives of both the government and producers to invest in research. In the alternative scenario; when a low weight is attached to producer welfare (i.e., $\theta < 1$), production will be taxed, producer research benefits will be lower, and taxpayer research benefits will be greater. However, when a relatively low weight on producer welfare is a consequence of a high opportunity cost of taxation, high taxpayer research costs are likely to be found when production is taxed and, therefore government incentives to invest in research will tend to be reduced when agriculture is taxed. Producer and government incentives to fund research are reduced when production is taxed. Regardless of whether producers are politically influential, the effects on both producer and public sector incentives to invest in research run in the same directions. That is, when production is taxed, both producers and government tend to have reduced incentives to invest in agricultural research; when agriculture is subsidized,

[18]For many cases, the increase in producer benefits will be exactly equal to the decrease in government revenues. This is true for every case when the country is a small exporter or importer.

producer and government incentives to invest in agricultural research tend to be greater.[19] This result is likely to hold at least as a general tendency for a large number of scenarios.

Summary of Theoretical Results

In summary, as suggested by Gardner (1988), the driving force for both the research and price policies is the political economy process (represented here as the welfare weights). The interaction between the policies serves to modify the impacts but is likely to be of secondary importance. On this view, the major role of price policies may be as an indicator of the forces at work rather than as a primary cause. Low rates of public sector investment in research are likely to be found where the government perceives a high opportunity cost of government revenues. These will be places where agricultural production is taxed, a policy that both reflects that perception and indirectly diminishes the private and public sector incentives to invest in agricultural R&D. On the other hand, cheap food policies might also involve implicit taxes on agricultural producers and these might coincide with a greater propensity for research.

Theory is ambiguous about the relationship between summary measures of price distortions and research investments for several reasons. First, there is some disagreement among economists about whether producers benefit from research-a result that depends in large measure on the nature of the research-induced supply shift. Second, summary measures of protection don't reflect differences of distributional impacts among policy instruments that may be very important, especially when there are more than two interest groups. Third, policy impacts vary according to trade status and elasticities of supply and demand. Theoretical results also vary with the form chosen for the trade-off of welfare among interest groups. Finally, further complications arise when allowance is made for other objectives of government that always arise in research priority setting exercises and have not been included in the analysis (e.g., food security, trade balance, regional impacts). Some of this ambiguity can be resolved by the development of a more complete theory that does not rest on summary measures of protection but instead allows for joint optimization of research and other specific instruments of

[19] Gardner (1988, p. 33) shows that research spending is accelerated when producers benefit from research and producer welfare is relatively heavily weighted.

policy. Some of the issues cannot be resolved by theory. They are empirical questions that must be addressed empirically.

4.6 Empirical Evidence

There have been relatively few studies that have looked directly at the connections between prices and productivity or prices and research investments.[20] Fulginiti and Perrin (1992) investigated the effect of prices on productivity in 18 less-developed countries using data from 1960 to 1984. They concluded that price policies have had a significant negative impact on agricultural productivity and eliminating price distortions would lead to significant increases in agricultural productivity. This is consistent with the view cited above and with the World Bank (1983) which reported that high-distortion countries had economy-wide growth rates about two percent lower than average.

Alston and Pardey (1993), following Pardey, Roseboom, and Anderson (1991, p. 297) regressed national agricultural research intensities for a wide range of countries against a number of explanatory variables, including measures of the rate of protection. They found that *higher* rates of protection were associated with lower investments in public sector agricultural research, in contrast with their expectations (but a result that was not ruled out by their theoretical development). One difference between their analysis and that of Fulginiti and Perrin (1991) was that Alston and Pardey (1993) used price distortions (nominal rates of protection) rather than prices *per se*. With some policy instruments (e.g., a variable levy), changes in the rate of protection may be inversely correlated with production incentives. Thus, prices, rather than rates of protection, might be the more appropriate explanatory variable for R&D investments.

In conclusion, then, the existing econometric evidence is mixed. More empirical work is need in order to establish more clearly, and more persuasively, the effects if any of price policies on agricultural productivity, either through impacts on agricultural R&D or through other mechanisms.

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[20]Some economists view prices per se as less important as determinants of research investments. For instance, Gardner (1988) de Gorter, Nielson and Rausser (1992). and Roe and Pardey (1991) view research funding as the outcome of a political economy process in which price policies and research policies are jointly endogenous. These studies and others have provided some analytic results, and their premise is congenial.

5. POLICY IMPLICATIONS AND RESEARCH PRIORITIES FOR OECD

5.1 Multinational Considerations in Agricultural R&D

A number of policy issues arise in relation to agricultural research that have multinational implications. Here we introduce two related ideas that both pertain to the international spillovers of impacts of R&D and the implications for the role of a multinational cooperative approach to agricultural R&D.

Firstly, the intervention by countries in their own agricultural markets does have implications for the size and distribution of benefits from technological change internationally and therefore for the rate and factor bias of technological change in agriculture, both in the country that intervenes and in other countries. Thus, for example, the subsidization of grain exports by the U.S. and EC may have encouraged wheat research in those countries but will have, at the same time, discouraged R&D in other countries, such as Australia, that do not subsidize. However, the appropriate response is to correct the market distortion itself rather than to distort the technology choices. That is, an additional reason for wanting to correct the distortion in the international grains market is to mitigate the distortion in the international pattern of R&D investments.

Secondly, there is a general problem of market failure in the provision of international public goods such as agricultural R&D. In particular, one country's investment in a particular line of R&D may lead to benefits in other countries either because the other countries benefit from lower world prices for the commodities concerned or because the other countries can adopt the results of the research and benefit as producers. That is, there can be both pecuniary and technological spillovers. This type of issue was illustrated graphically by Alston and Mullen (1992) for the example of Australian wool research where the Australian incidence of costs was much higher than the Australian incidence of benefits (an outcome that was exacerbated by the particular arrangements in Australia for funding the R&D).

Again, the appropriate response is to develop an international institution to deal with the market failure rather than to distort the technological choices. In the absence of the institution, however, the technological choices will continue to be distorted. Both of these issues transcend the interests of individual countries but concern all countries and both, therefore, seem to be appropriate issues to be considered by an organization such as the OECD. It seems likely that both will contribute to a tendency to under-invest, globally, in agricultural R&D.

5.2 Rates of Return to R&D

That distortions in agricultural R&D are important may be conveyed more clearly by a consideration of the evidence on rates of return to agricultural R&D. Echeverría (1990) has documented the results of a large number of studies of rates of return to agricultural research. The overwhelming conclusion from that collection of results is that estimated rates of return to agricultural research have been very high, typically well in excess of 20 percent per annum. The corollary is that there appears, in general, to have been a gross under-investment in agricultural research. This, at least, is the conventional view; there are grounds for suspecting that the published rates of return may have been biased up. Most of those studies have not adjusted for the effects of price distorting policies on the measures of research benefits, an omission that might lead to over- or under-statement of the benefits and the rate of return (Alston, Edwards and Freebairn 1988). Most have not adjusted for the effects of the excess burden of taxation on the measures of costs, an omission that will lead to a systematic understatement of the social costs and an overstatement of the social rate of return (e.g., Fox 1985, Dalrymple 1990). Most have estimated average rather than marginal rates of return, and it is the latter that is relevant for investments. Private sector research is often omitted from the analysis. Further work is needed to improve the existing estimates and make adjustments so as to eliminate the doubt arising from measurement issues.

Even allowing for adjustments of these types, it seems likely that the rate of return to agricultural R&D has been high and that there has been some underinvestment. Some of the results point to some other general tendencies: livestock research tends to earn a lower rate of return than crops research and more basic (pretchnology) research tends to earn a higher rate of return than more applied research.

Table 5.1 shows a selection of estimates of rates of return to investments in agricultural R&D for OECD countries. As with the more general set of studies surveyed by Echeverria (1990), the rates of return in these OECD studies are generally high. In several of these studies there has been a correction for the impact of government policies and so on.

Table 5.1: *Rates of Return to Agricultural Research in OECD Countries*

	Study				
country	Author	Year	Commodity	Period	Rate of Return
Australia	Duncan	1972	pasture improvement	1948-69	58-68 %
Canada	Fox et al.	1989	dairy	1968-84	97%
Canada	Widmer et al.	1988	beef	1968-84	63%
Canada	Zachariah et al.	1988	broilers	1968-84	48%
Finland	Sumelius	1987	aggregate	1950-84	21-62%
Germany, FR	Burian	1992	aggregate	1950-87	21-56 %
Ireland	Boyle	1986	aggregate	1963-83	26%
Japan	Hayami and Akino	1977	rice breeding	1932-61	73-75 %
New Zealand	Scobie and Eveleens	1987	aggregate	1926-84	15-66 %
UK	Thirtle and Bottomley	1988	aggregate	1950-81	70%
USA	Huffman and Evenson	1992	crop and livestock	1949-82	>45%
USA	Lyu, White and Liu	1984	aggregate	1949-81	66%

Source: Boyle (1986); Burian (1992); Duncan (1972); Fox, Roberts and Brinkman (1989); Huffman and Evenson 1992 Scobie and Eveleens (1987); Sumelius (1987); Thirtle and Bottomley (1988); Widmer, FOX and Brinkman 1993 Zachariah, Fox and Brinkman (1988).

5.3 Conclusion

This paper has discussed structural change in OECD agriculture, with an emphasis on the role of technical change as a component of structural change, and what the literature has established about the role of commodity price policies in influencing the pattern of investments in agricultural R&D and the rate and direction of research-induced technical change. The paper is a preliminary look at these questions, written with a view to assisting in the identification of the key elements that ought to be involved in a more comprehensive analysis to be undertaken later. It is the conclusion of the authors that the issues are important, the linkages are strong and poorly understood, and that a significant investment of further analysis is easily justified.

The available data indicate that productivity growth has been the major source of growth in output in OECD agriculture, in some cases even preventing a decline in output that would have occurred as a result of other changes. The other changes contributing to structural change in agriculture, primarily growth in nonfarm wages drawing labour out from agriculture, would have led to higher food prices; yet agricultural productivity growth has been such that food prices have fallen. Prices received by farmers for their products have been falling in real terms and falling relative to the prices farmers pay for their inputs.

Productivity growth, arising from technical change, has been veryimportant. The nature of technological change has been different in different countries. In some countries the pattern has been fairly factor-neutral whilst in certain others it has been very biased (primarily labour-saving); some countries have experienced much greater productivity growth than others have. The causes of these patterns are poorly understood. The implications for structural change also are poorly understood. A great deal more work is needed, including simply gathering data and constructing accurate measures of agricultural inputs and outputs, and productivity and its growth, before we can say much about why past changes have occurred, which is a first step toward predicting with confidence the structural implications of future policy changes.

We have obtained some data on the patterns of public-sector investments in agricultural R&D in OECD countries, and those data reveal some very significant differences among countries. While there is a tendency, globally, for richer countries to invest relatively more in public-sector agricultural research, that tendency accounts for only a small proportion of the variation in agricultural research intensity ratios. More effort is warranted to strengthen our understanding of the causal link between other policies, and R&D policies, and the rate and direction of growth in agricultural productivity and the structure of agriculture.

In summary, (a) technological change in agriculture is an ongoing fact of life that has important structural consequences, (b) agricultural policies probably affect the rate of technical change along with the total benefits and their incidence, and (c) the process of technological change, its economic implications, and its causes and consequences, are not fully understood and demand attention. A significant commitment of effort and resources is indicated to document the role of agricultural R&D and new technology in structural change in agriculture, and to enhance the understanding of the role of technology, and appropriate domestic and international agricultural policies.

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