CHAPTER 7

Agricultural Productivity in the United Kingdom

Jenifer Piesse and Colin Thirtle

1. INTRODUCTION

For much of 2008, soaring food commodity prices made headlines in the news. Rising prices are the market's signal that supply is not keeping pace with demand, so the events of 2008 have led to a reappraisal of the world's ability to feed itself. In a recent review (Piesse and Thirtle 2009) of the events of 2008, we showed that world food security is not a foregone conclusion. The long-standing conventional wisdom that science increases supply faster than population and income growth increase demand has to be questioned. With this in mind, we distinguish between three productivity measures, as their implications differ. These are yields, which, with area harvested, determine output; labor productivity, which correlates with incomes; and total factor productivity (TFP), which distinguishes between technical progress, efficiency change, and input intensification. Hence TFP growth has different implications depending on the cause.

2. OUTLINE

To put the chapter in context, the next section gives a very brief account of the main policy changes in the United Kingdom that have affected agricultural

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productivity since the Second World War. Section 4 is historical, covering partial measures, that is, yields and labor productivity. Section 5 explains the current UK TFP methodology, followed by the full TFP results and analysis. The limitation of the national TFP is that it cannot be decomposed by region or crop. Thus, Section 6 presents regional data, but only for the eastern counties of England and only from 1970 to 1997. This is at the crop level and shows the importance of crop switching to increasing TFP. Then, Section 7 covers the international productivity comparisons that are most relevant. These are for the United States and the European Union (EU) countries and for the older EU members and those that acceded in the last few years. Section 8 offers explanations of the productivity changes in the United Kingdom, and the final section summarizes the results and notes the limits of our knowledge in this area.

3. POLICY CHANGES AND LIVESTOCK DISEASES

During the Second World War (WWII), agriculture was subjected to state control, which included compulsory cropping orders, land reclamation, and the eviction of inefficient farmers. Food was rationed and animals were slaughtered because feed was too scarce to keep them. Thus, arable output was maximized, as the main objective was to reduce imports to save shipping space, which was essential to the war effort. By the end of the war the United Kingdom was bankrupt and in debt, so recovery was slow, and state control of agriculture and food rationing was not ended until 1953-54 (Self and Storing 1962). This was followed by a long period typified by cooperation between the state and agricultural organizations, and support was provided by producer subsidies and marketing boards.

This situation persisted until UK membership in the European Community, and new arrangements were phased in beginning in 1973 (Hill 1984). The Common Agricultural Policy (CAP) replaced subsidies with variable levies, which in most cases increased prices for producers as well as consumers. The increased profitability may be expected to have an impact on agricultural investment and productivity. The CAP levels of support were extremely expensive for the taxpayer and led to surpluses that exacerbated the situation because of high storage costs. This led to restrictions such as milk quotas beginning in 1984, which heralded a new era of low profits. Policy moved away from encouraging production and toward environmental stewardship. EU policies such as the set-aside requirement followed in 1992 under the MacSharry reforms and led to the decoupling of output and agricultural support payments.

These policy changes were accompanied by a marked change in agricultural R&D expenditures, which had grown at 7% per annum from the end of the war to the early 1980s but then dropped in real terms because of the Thatcher government's antipathy to the public sector. By the end of the decade, expenditures were fairly steady, but then in the 1990s there was a clear retargeting of agricultural R&D away from productivity-enhancing research and near-market research, which were deemed to be the responsibility of industry, and toward areas of public interest (Thirtle, Palladino, and Piesse 1997). The effects of these changes in policy can be seen in the analysis of agricultural productivity that follows. The Animal Disease Laboratory at Pirbright suffered heavy funding cuts in the 1980s before the appearance of bovine spongiform encephalopathy (BSE), commonly known as mad cow disease, in 1996 and foot-and-mouth disease in 2001, both of which prolonged the United Kingdom's slump in TFP growth.

4. PARTIAL AND TOTAL FACTOR PRODUCTIVITY IN HISTORICAL PERSPECTIVE

The agricultural history of the United Kingdom has attracted considerable attention since the realization that the world's first industrial nation had an agrarian revolution prior to the industrial transformation. From Karl Marx onward, the nature of these two revolutions that ushered in the era of modern economic growth has been hotly disputed. In fact, it is generally agreed that this was the second UK agricultural revolution, the first being much earlier in medieval times.

Historians estimate that the population of England may have tripled between 1100 and 1340, from 1.5 million to 4.5 million, and that such an increase was made possible by agrarian changes that can be claimed to constitute a revolution. Duby (1954) dated the revolution from about 800 to 1100, while White (1962) suggested 700 to 1000. Both placed most emphasis on improvements to the plough, the replacement of oxen by horses, and the switch from a two-course to a three-course rotation system. The two-course rotation reflects Mediterranean practices and means half the land is left fallow each year, while in England there is actually enough rain to sow a spring crop of oats, peas, or beans and get two-thirds of the land under cultivation in any year. Possibly the imperialist Roman invaders imposed the two-field system brought from their homeland, believing that all things Roman were of course superior to the habits of the barbarians.

The dating of the second agrarian revolution varies from 1760 to 1815 in early works covered by Grigg (1982) to 1750 to 1880 in later assessments

(Chambers and Mingay 1966). The advances most discussed include further plough improvements, use of seed drills (associated with agriculturist Jethro Tull), and more hoeing to control weeds. However, the mechanical innovations were not intended to be labor saving, as they were in America. Rather, labor use increased with a view to getting more output. Other key improvements were changes in crop rotations that featured nitrogen-fixing legumes like turnips (wrongly attributed to Viscount Townsend), which also helped feed the increasing number of animals following improved selective breeding (associated with Robert Bakewell). There was also a new development in the large-scale purchase of off-farm inputs, such as field drainage and the construction of new buildings, as well as purchased fertilizer and feed.

The changing rotations and selective breeding were made much easier by the change in land tenure arrangements as the open fields were converted into self-contained farms with fee simple tenancy. This allowed those who wanted to innovate to do so without the need for general agreement. At the same time the ownership changes were causally prior to capital expenditures, as owners could now appropriate the full returns to their investments. Thus, whereas Marx believed technical change was the driving force, modern institutionalists such as North (1990) make a convincing case that all else followed from getting the incentives right.

These stories are entertaining, but the statistical data on changes in output, yields, labor productivity, and TFP leave a lot to be desired. It was not until 1866 that the Board of Agriculture began an annual publication of labor force, land use, and livestock data, adding crop yields in 1885. Thus, there is little evidence on the output and productivity effects of the medieval agrarian revolution. Grigg (1982) reported a 200% increase in the population of England and Wales from 1700 to 1850 and a 264% increase in arable output. He estimated that 62% or almost two-thirds of this came from area expansion (including the reduction in fallow land), rather than yield increases. This is despite data that show that grain (mainly wheat) yields in East Anglia approximately doubled over the period, as the average would have been much lower.

Labor use and productivity is more emotive; Marx and others painted a grim picture of smallholders losing their common land to enclosures and being forced to seek work in the dark Satanic mills of Manchester and other rapidly growing industrial centers. There is now evidence that the agricultural labor force increased until 1850, which marks the turning point in the structural transforma-

tion at which point the decline in agricultural employment began. Even so, labor productivity grew as output outstripped labor growth. Grigg (1982) reported that output tripled from 1700 to 1850, while the labor force increased by between 50% and 75%, giving an annual labor productivity growth rate of 0.83% to 1.0%. He also stated that labor productivity grew at 1% per annum from 1800 to 1850, because of output growth, and then grew at the same rate from 1850 to 1900, mostly because of the decline in labor, as industrial employment outstripped population growth. This implies that labor productivity grew at almost 1.0% per annum in the 1700s and then accelerated slightly in the 1800s. There is plenty of disagreement on labor productivity. For instance, Brunt (2003) estimated that labor productivity grew at only 0.29% per annum from 1700 to 1775 and declined at 0.06% per annum from 1775 to 1845.

From 1880 on there are sufficient data to construct estimates per decade, and these are reported in Table 7.1. In the 1880s the decline in ocean freight rates opened the United Kingdom up to competition that had been expected ever since the repeal of the Corn Laws in 1846, which signaled the end of protectionism. First grain imports from Russia and the North American prairies and then meat from the antipodean dominions ended the age of high farming. Labor productivity stuttered and then rose at an increasing rate as the mechanical revolution allowed increasing amounts of labor to enter industrial employment. However, it is not until WWII that growth exceeded 1%, making the earlier estimate seem high.

Data on yields are patchy before 1850, and we rely on Grigg's (1982) best guess that arable yields in England grew at 0.5% per annum from 1700 to 1850. Brunt (2003) was again less optimistic, putting yield growth from 1705 to 1775 at 0.3% per annum and, importantly, arguing that it stayed the same from 1775 to 1845, which must include the key period of the agrarian revolution. The even more contentious issue is the previous century, in which data from Norfolk and Suffolk suggest a 1% per annum growth rate in the first two-thirds of the century, before legumes and clover were added to the rotations. The data again cover the post-revolution period, showing low and erratic growth rates, averaging 0.15% per annum for the periods before WWII. Then, yield growth jumped to new levels entirely (see Table 7.2).

Table 7.1. Output rate of increase per male worker, 1880-1960 (% per annum)

	1880-1890	1890-1900	1900-1910	1910-1920	1920-1930	1930-1940	1940-1950	1950-1960
Increase	0.8	0.25	-0.2	0.7	0.7	2.2	2.4	2.9

Sources: Grigg 1982; Hayami and Ruttan 1971.

Table 7.2. Rate of increase in output per hectare, 1880-1960 (% per annum)

	1880-1890	1890-1900	1900-1910	1910-1920	1920-1930	1930-1940	1940-1950	1950-1960
Increase	0.2	-0.5	0.35	0.2	0.5	1.7	1.4	1.9

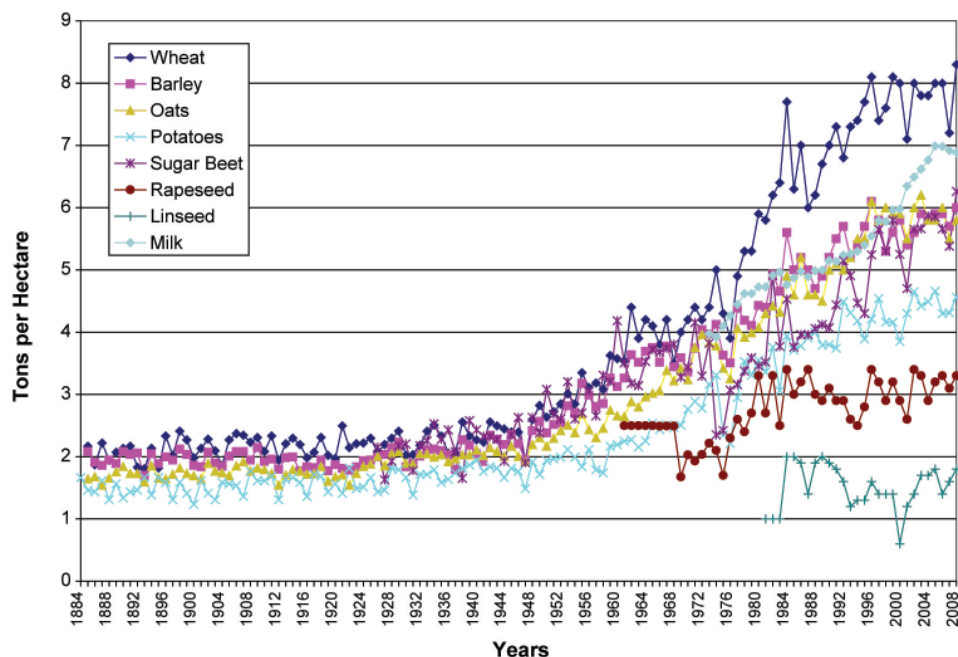*Sources:* Grigg 1982; Hayami and Ruttan 1971.

Figure 7.1. Yields of main crops and milk, United Kingdom
Sources: See Data References Appendix.

Yield data are available for the main crops from 1885 onward, and as Figure 7.1 shows, these data confirm the impression given by Table 7.2 that yields of wheat, barley, oats, and potatoes grew very little prior to the end of WWII. The mean growth rate, reported in Table 7.3, is only 0.27% per annum. Only sugar beets, which was then a new crop, had a higher growth rate of 0.79% per annum from 1925 for the period reported.

Thus, the first structural break appears with the application of plant science after WWII, when research-led productivity growth had its golden age. Until the 1990s, the growth rate of the four major crops was about 2% per annum, rather than 0.2%. Sugar fared even better, growing at almost 5% per annum until 1973 and then at almost 2% for the rest of the period. Sugar is a separate crop, grown under the auspices of the British Sugar Corporation (BSC), which has become part

Table 7.3. Annual growth rates of crop yields (% per annum)

Years	Crop	Growth Rate	t Stat	Adj R^2
1885-1945	Wheat	0.24	4.24	0.22
	Barley	0.14	2.78	0.1
	Oats	0.37	8.39	0.54
1948-1996	Wheat	2.31	20.73	0.94
	Barley	1.76	26.4	0.94
	Oats	2.02	34.88	0.96
1996-2008	Wheat	0.12	0.33	0.01
	Barley	0.27	0.89	0.07
	Oats	-0.29	-01.13	0.1
1961-1987	Rapeseed (Canola)	1.25	3.0	0.24
1987-2008	Rapeseed	0.38	1.25	0.03
1985-2008	Linseed	-0.09	-1.21	0.02
1884-1945	Potatoes	0.34	5.26	0.3
1948-1992	Potatoes	1.98	18.29	0.89
1993-2008	Potatoes	0.58	2.1	0.19
1973-2008	Milk	1.53	27.16	0.96
1925-1945	Sugar	0.79	1.61	0.08
1945-1973	Sugar	4.94	5.69	0.57
1976-2008	Sugar	1.91	12.08	0.82

Sources: See Data References Appendix.

of Associated British Foods. Here, R&D was funded by BSC, with a matching levy (mandatory check-off scheme) imposed on farmers. The success of this arrangement, with most of the research being conducted at the Broom's Barn research station of the Biotechnology and Biological Sciences Research Council (BBSRC), which is dedicated to sugar, is reported in Thirtle 1999.

Aside from sugar beets, the other main crops have a second break point in 1996, or 1993 for potatoes. After these dates, the growth rate for potatoes falls to 0.58% and for the cereals it returns to about 0.2%, just as it was before the advent of publicly funded research after WWII. The reasons for this reversal have been investigated previously by Thirtle et al. (2004a) and will be considered in Section 10. With the benefit of hindsight and more data, it can be said that UK R&D expenditures declined from 1982 and were targeted away from productivity enhancement, so it seems likely that after 14 years this policy change has had a serious impact. However, there are other explanations, including the possibility that ongoing, rapid

productivity growth is a passing phase and not a foregone assumption. The recent scientific revolution has lasted no longer than its predecessors in the UK case, but is this caused by the funding cuts, or is there a return to the historical growth path as the scientific revolution enters its late phase?

The final issue is total factor productivity (TFP), or appropriately weighted aggregate output per unit of appropriately weighted aggregate inputs. Brunt (2003) estimated TFP growth despite the lack of data. His estimates show a rate of TFP growth of 0.17% for the period 1705 to 1775 and -0.01% (that is zero, statistically speaking) from 1775 to 1845. Other estimates of TFP growth for the second period range from 0.24% per annum to 0.67%. We noted earlier one reason why they are fairly low, namely, that there was an increase in non-farm inputs and some level of capital accumulation, which Grigg (1982) showed more than tripled from the 1760s to the 1850s.

5. RECENT PARTIAL AND TOTAL FACTOR PRODUCTIVITY

The crop-specific data reported in the previous section straddles the ancient past and recent times, as it begins in 1884 and continues to 2008. From 1953 onward it is possible to report consistent series on outputs, inputs, yields (measured as value of output per hectare), output per worker, and TFP using decent annual data and established methods (Tornqvist-Theil index and Fisher's ideal index). This is an update of a report by Thirtle et al. (2004b), which in turn was extracted from a report (Thirtle et al. 2003) to the Department of the Environment, Food and Rural Affairs (DEFRA). The older material was first published in an article by Thirtle and Bottomley (1992).

From 2000 to 2003 the Ministry of Agriculture, Fisheries and Food (MAFF, replaced in 2001 by DEFRA) funded a project to upgrade the statistics used for productivity measurement. Details are in the report by Thirtle et al. (2004b) but the methodology is briefly noted in this chapter. The result is that DEFRA now uses methods almost identical to those of the U.S. Department of Agriculture (USDA), as we advised DEFRA in conjunction with Eldon Ball. The only major difference is that the USDA uses Fisher's ideal index rather than the Tornqvist-Theil index, because it better fit the USDA's system. This does not affect results much in our experience, so our TFP is our own Tornqvist from 1953 to 2000, updated to 2008 using the DEFRA index.

We begin by reporting the output, input, TFP, land, and labor productivity indexes and then look at outputs and inputs at various levels of aggregation. Table 7.4

Table 7.4. Output, input, TFP, labor, and land productivity indexes,
1953-2008

Years	Output Index	Input Index	TFP	Labor Productivity	Land Productivity
1953	100	100	100	100	100
1954	105.7	105.1	100.5	107.3	105.9
1955	103.7	103.2	100.5	110.8	103.9
1956	110.7	104.6	105.9	122.4	111.0
1957	112.2	107	104.9	125.5	112.7
1958	113	106	106.6	129.1	113.6
1959	118.3	107.1	110.4	139.3	119.5
1960	122.5	106.8	114.7	150.1	123.8
1961	127	108.6	117	162.4	129.2
1962	133.8	109.6	122	173.9	136.1
1963	135.3	109.6	123.5	181.3	137.7
1964	131.3	105.3	124.7	186.1	133.4
1965	133.1	104	128	194.7	135.3
1966	133.5	101.3	131.7	207.5	135.6
1967	137.8	99.9	137.9	225.4	140.2
1968	138.9	100.2	138.5	228.6	142.2
1969	143.7	103.1	139.4	244.6	145.8
1970	148.7	105.8	140.6	268.5	154.6
1971	152.7	105.5	144.8	260.1	158.8
1972	153.9	106	145.1	268.4	160.7
1973	155.7	105.2	148.1	266.7	163.0
1974	160	106	151	279.4	167.3
1975	154.4	109.5	141.1	274.5	161.7
1976	149.4	109.6	136.3	270.9	156.4
1977	159.3	108.5	146.8	296.2	168.1
1978	166.6	108.8	153.1	312	175.7
1979	169.1	111.7	151.3	323.4	178.5
1980	173.6	110.3	157.4	340.9	182.1
1981	173.4	107.6	161.2	350.1	183.3
1982	182.3	110.3	165.3	374.8	192.9
1983	181.8	113.4	160.3	377.6	192.9
1984	195.7	112.7	173.6	420.8	207.8
1985	190.6	113.5	168	415.5	202.6
1986	191.4	113.8	168.2	437.4	203.7
1987	190.3	113.7	167.5	441.7	203.2
1988	189.3	113.7	166.5	453.4	202.6
1989	191.6	111.9	171.2	476.9	205.3
1990	190.9	110.8	172.2	486.1	205.0
1991	194.1	111.2	174.5	510.8	208.8
1992	194.7	109.5	177.8	532	210.9
1993	189.2	108.2	174.8	533.1	210.7
1994	191.1	108.4	176.3	556.5	213.4
1995	192.6	111	173.6	578.2	215.4
1996	190.8	111.3	171.4	584.3	211.8

Table 7.4. Continued

Years	Output Index	Input Index	TFP	Labor Productivity	Land Productivity
1997	188.4	109.6	171.9	587.4	208.2
1998	188.6	108.6	173.6	601.4	205.1
1999	189.9	107.2	177.2	627.9	209.6
2000	187.2	105.5	177.5	679	209.7
2001	179.7	104.0	172.9	609.1	198.6
2002	186.6	101.1	184.8	900.4	206.8
2003	184.8	98.5	187.6	911.9	205.4
2004	186.1	99.5	187.3	894.2	207.1
2005	188.7	97.4	193.8	1040.2	209.2
2006	182.7	94.8	192.6	1048.4	199.5
2007	180.5	94.7	190.6	985.2	198.0
2008	188.9	96.4	196.0	1108.8	207.1

Sources: See Data References Appendix.

begins with the output index, which starts from the conventional arbitrary value of 100 and rises to 188.9, so output increased by 89% over the full period. Inputs, in the second column, actually fell by 2.6%, so productivity has increased, as the third column shows, to 196, which is a gain of 96%. Output per unit of land, or yields, more than doubled, and labor productivity increased enormously, to 1108, or a little over 11 times its initial value. The huge difference between TFP and yields relative to labor productivity results from the substitution of other inputs for labor, which is a leading feature of developed country agricultural progress.

Figure 7.2 plots all the indexes except labor productivity (which has a larger scale) and makes interpretation much easier. The decline in output and TFP caused by the droughts of 1975 and 1976 can be seen clearly in the yield and output series, but apart from this period of unusually poor rainfall, output, yield, and TFP rise at a fairly steady rate until 1984. At that point, output and yield growth ceased and the TFP grows much more slowly, powered by the slight decline in inputs. Output does not recover until the last food price crisis year of 2008, and even then it is still below the average levels for the 1980s and 1990s. Yields do not recover at all and in 2008 were still as low as in 1984. However, comparison with Figure 7.1 and Table 7.3, for individual crop yields, suggests that 1984 was in fact a particularly good year and that the yield decline may be better dated from the mid-1990s. Until then growth was slower but positive, whereas after that date it appears to actually be negative. For inputs, the structural break seems to be at 1996, when slow growth turned to quite rapid decline.
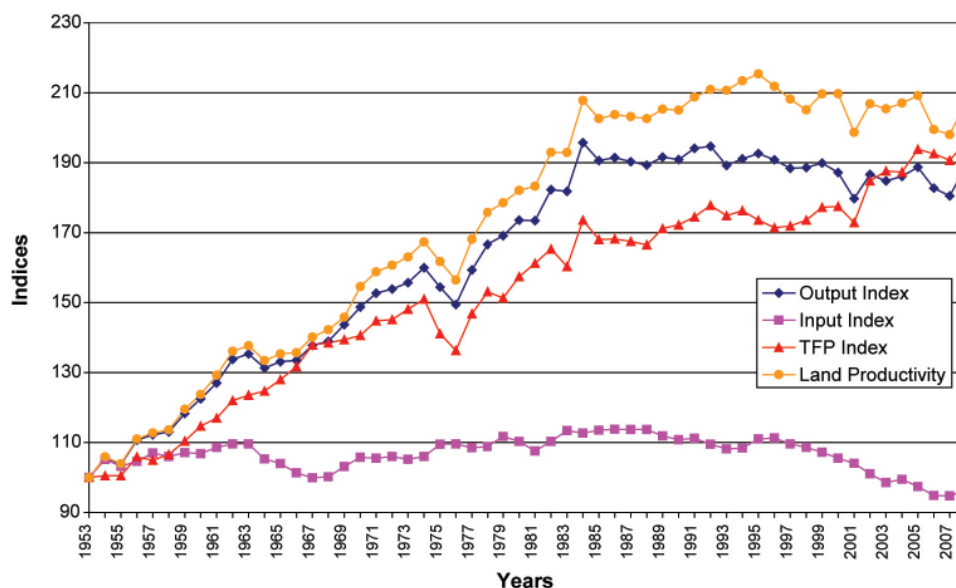
Figure 7.2. Output, input, and TFP indexes
Sources: See Data References Appendix.

Having identified these turning points in the series,[1] we use this information to construct the annual average growth rates in Table 7.5. Over the full period, output grew at 1.10% per annum, while inputs were unchanged, with a negative growth rate of 0.04% per annum, which is statistically insignificant (note the lack of fit too: the adjusted R^2 is 0.004). Since TFP is the ratio of these series in logarithms, it grows at 1.14% per annum, which is a lower growth rate than earlier studies reported. Thirtle and Bottomley (1992) estimated TFP growth at 1.77% per annum up to 1990, and Amadi (2000) and Barnes (2002) both covered the period to 1995, with estimates of 1.81% and 1.93%, respectively.

The reason for lower growth rates of output and yields in this study is the poor recent performance. The first column of Table 7.5 shows that since 1984 output has declined at 0.02% per annum, and the fourth column shows that yields declined at 0.03% per annum over the same period. Note too that output follows yields very closely, which is because the area harvested varies very little. Indeed, the adjusted R^2 is 0.995, so the variance in output is almost entirely ex-

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[1]This does appear to be a clear break in both the output and TFP series. However, statistical tests, based on the latest techniques in time-series econometrics, fail to determine that there is a break. This suggests that the length of series that is required for such tests makes them of little value in this type of investigation.

Table 7.5. Annual average growth rates (% by period)

Years	Output Index	Input Index	TFP Index	Output per Unit of Land	Output per Unit of Labor
1953-2008					
Growth rate	1.1%	-0.04%	1.14%	1.31%	3.96%
t Statistic	15.54	-0.88	24.31	18.10	58.17
Adjusted R^2	0.81	0.004	0.91	0.85	0.98
1953-1984					
Growth rate	1.87%		1.67%	2.08%	
t Statistic	29.65		22.23	32.78	
Adjusted R^2	0.96		0.94	0.97	
1953-1996					
Growth rate		0.19%			
t Statistic		6.06			
Adjusted R^2		0.45			
1953-2000					
Growth rate					3.86%
t Statistic					51.53
Adjusted R^2					0.98
1984-2008					
Growth rate	-0.02%			-0.03%	
t Statistic	-4.88			-0.52	
Adjusted R^2	0.49			0.01	
1984-1996					
Growth rate			0.30%		
t Statistic			2.30		
Adjusted R^2			0.26		
1996-2008					
Growth rate		-1.42%	1.21%		
t Statistic		-15.13	9.53		
Adjusted R^2		0.95	0.88		
2000-2008					
Growth rate					6.40%
t Statistic					4.59
Adjusted R^2					0.71

Sources: See Data References Appendix.

plained by yield changes. However, the lower TFP growth rate is more complicated. Column three of Table 7.5 shows that TFP growth was slower than the older estimates even over the period from 1953 to 1984, when it was growing fastest, at 1.67% per annum. Then the rate fell to only 0.3% per annum until 1996. It has recovered to 1.21% since 1996. The decline in TFP growth in the early period re-

flects the complete overhaul of the UK productivity data reported in Thirtle et al. (2004b), which gave a growth rate from 1953 to 2000 of 1.26% per annum. The increased level of detail in the new DEFRA data picks up more quality change, and when this is properly measured, less is attributed to TFP growth.

Figure 7.2 also shows that the recent recovery in TFP is not driven by output growth but by falling inputs. The second column of Table 7.5 reports that inputs grew at 0.19% per annum until 1996, and since then they have fallen at 1.42% per annum, which is a rapid decline in TFP accounting terms. The last column of Table 7.5 is also relevant here, as it reports labor productivity growth, and it is the rapid fall in labor inputs that drives TFP growth in the developed counties. Labor productivity is plotted in Figure 7.3, along with the yield index, to show how much faster it has grown. This was at 3.86% per annum until 2000, but since then it has jumped to 6.4% per annum. Labor productivity can be expected to rise when machinery and equipment are increasingly being substituted for labor, but this has not been the case. Indeed, Fuglie (2008) identified a decline in agricultural investment as a key driver of productivity growth in the recent past. Since a large part of investment is machinery, it seems likely that this has been decreasing, and we investigate this next.

The changes in the component parts of the output and input indexes are shown in the columns on the left side of Table 7.6. We begin by reporting average shares
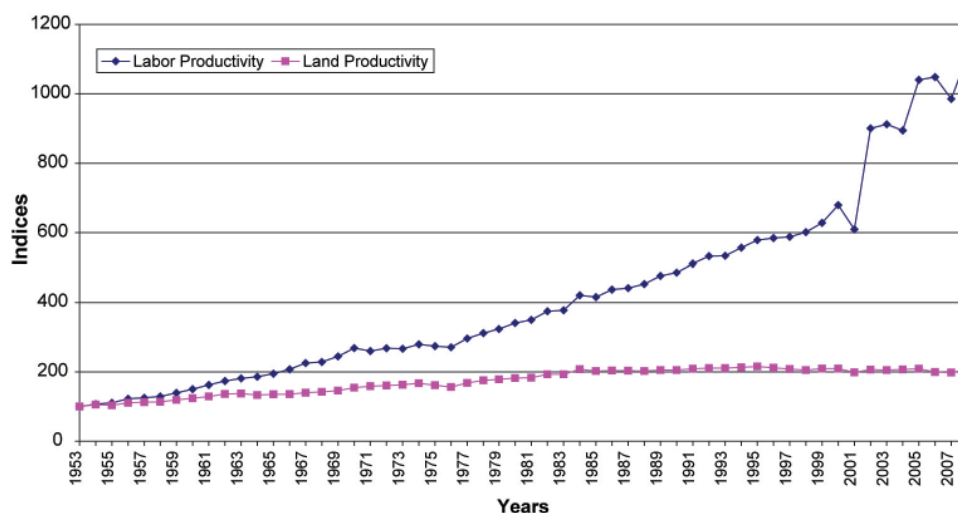

Figure 7.3. Land and labor productivity
Sources: See Data References Appendix.

Table 7.6. Shares in revenue or costs and annual mean growth rates

	Shares in Revenue or Cost (%)				Annual Average Growth Rates (%)		
	1953-2000	1953-1984	1984-2000	2008	1953-2008	1953-1984	1984-2008
Outputs							
Crop outputs	22	20	26	29	1.68	1.70	0.04[b]
Horticulture & fruit	11	10	11	13	0.12	0.55	-0.68
Livestock	38	38	39	36	1.16	1.83[a]	0.63
Livestock products	29	32	24	22	0.43	1.67	-0.53
					1953-2008	1953-1996	1996-2008
Inputs							
Seeds	2	2	2	4.5	0.84	1.00	-0.60
Fertilizers	7	7	7	11.0	1.13	2.20	-5.90
Pesticides	2	1	4	4.7	2.85	3.37	-0.69
Feed	23	25	20	28.3	1.00	1.24	0.85
Miscellaneous	6	6	7	9.4			
Machinery	20	19	20	9.0	-0.37	-0.10	-1.39
Buildings	9	7	14	5.1	2.30	3.28	-0.57
Labor	22	26	14	18.2	-2.10	-2.04	-3.21
Land	4	3	6	9.7	-0.13	-0.19	0.22

Sources: See Data References Appendix.
[a]For livestock output the sub-periods are 1953-1995 and 1995-2008.
[b]Not significantly different from zero.

in total revenue, from 1953 to 2000, so that the relative importance of each output can be judged. The shares show that animal products have declined in importance while crops have become more important, but even so this has only reduced the share of animals and animal products from 67% of total revenue to 63%. Updating to 2008 shows that by the final year, animals and animal products had declined further, to only 58% of total revenue, but we will see next that this is the result of an unusually high level of cereal output in response to the high prices of 2008.

The columns on the right side of Table 7.6 report that over the full period, from 1953 to 2008, crop output grew at 1.68% per annum, livestock at 1.16%, and livestock products at 0.43%, while horticulture and fruit output was virtually stagnant, growing at only 0.12% per annum. UK producers have lost market share to imports, as these items have increased their share in consumer expenditures. Even in the early period, prior to 1984, there was little growth in horticulture and fruit, while the other three outputs grew at a minimum of

1.67%, as can be seen in Figure 7.4. After 1984, only livestock output grew, with crops stagnant, livestock products falling at 0.5% per annum, and horticulture and fruit output falling at 0.68% per year. This sector has experienced the most rapid and severe withdrawal of public R&D and the biggest gains in exports. The intermediate inputs are reported next in Table 7.6 and plotted in Figure 7.5. The figure shows that the two rapidly growing inputs were fertilizer and pesticides. Growth of pesticides overtakes that of fertilizer in the early 1980s, but by the early 1990s growth has peaked for both. The feed index includes other animal inputs, such as veterinary expenses. Table 7.6 shows that feed inputs began as a big share and retained that importance despite slow growth, while fertilizer and pesticides are relatively unimportant. The rise in the shares of the intermediate inputs in 2008 is mostly due to the huge fall in the capital items, which we cover next.

   The structural breaks in the input series occur around 1996, which is when the aggregate input index turned down, so for simplicity this is the date used in Table 7.6. The outcome is not affected, since it is clear that growth was faster before 1996 and since then only feed continued to grow, while fertilizer declined rapidly, at over 5% per annum. This decline is exacerbated by the high prices in the final year, but this is a minor point.
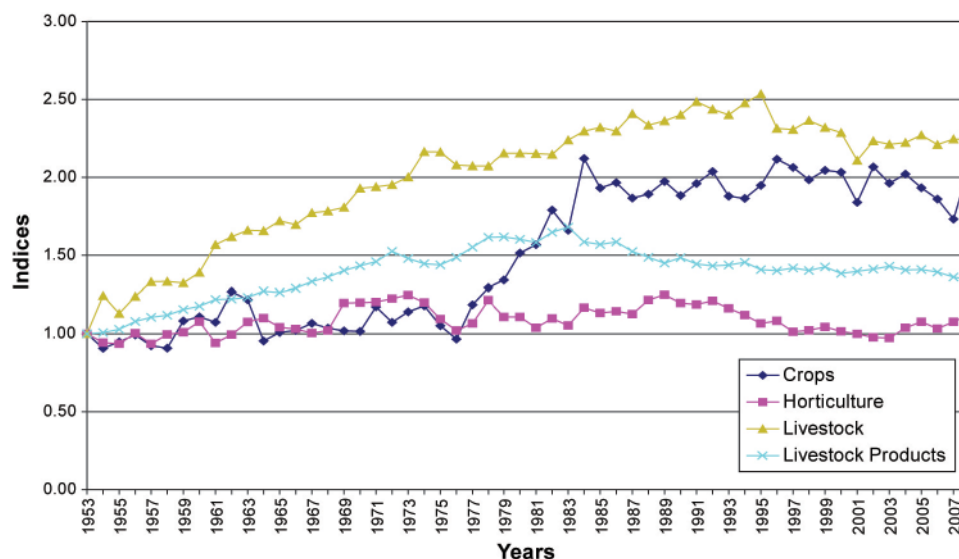

Figure 7.4. Output indexes
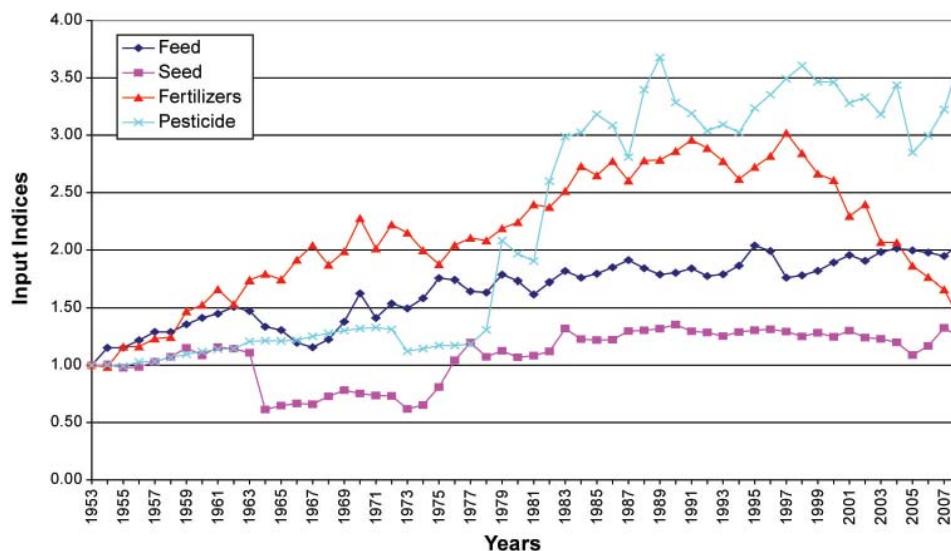*Sources:* See Data References Appendix.

Figure 7.5. Intermediate input indexes
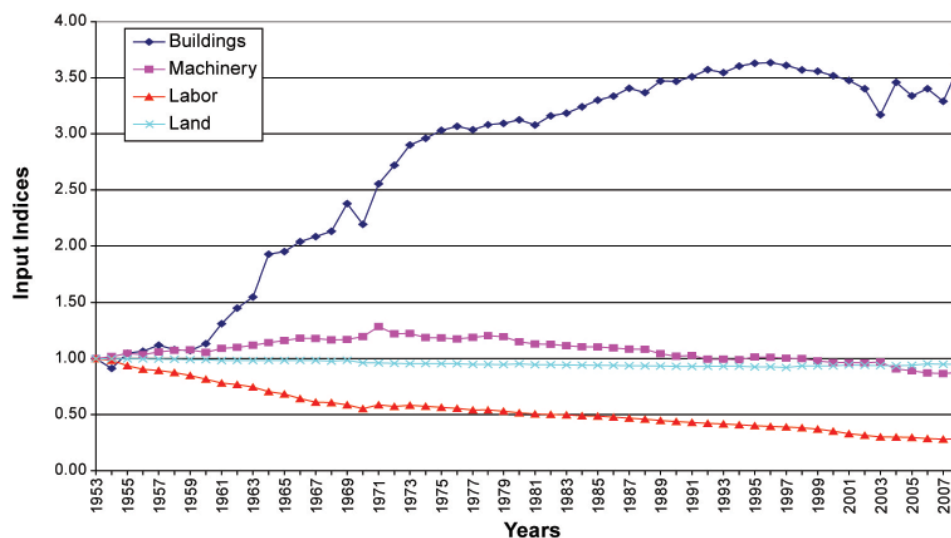*Sources:* See Data References Appendix.

Figure 7.6. Land, labor, and capital indexes
Sources: See Data References Appendix.

Finally, Figure 7.6 plots the inputs of land and labor and the capital inputs. It clearly shows the rapid growth of buildings and land improvements, in contrast with the rapid reduction in labor, which typifies developed country agriculture. Thus, in Table 7.6, the share of buildings and land improvements in total costs doubles over the two periods, while that of labor is practically halved. Machinery maintains its share but grows very little, while land's share doubles by 2000.

Table 7.6 reports that inputs for buildings grew at 3.28% in the early period while labor fell at over 2% per annum. Land is almost constant throughout and machinery declines slightly. A startling aspect of these data are the results from 1996 to 2008, which show that labor's rate of decline has risen to over 3% per annum. It is difficult to conclude how this is being achieved, since the machinery input is itself declining at 1.39% per annum and buildings and land improvements at 0.57% a year. Could it be that the influx of labor from the new EU member states has not been fully recorded?[2] Thus, by 2008, the shares of the capital investment items are incredibly low by historical standards. There appears to have been a dramatic decrease in investment, which also shows in the capital assets section of DEFRA's (2008) accounts.

6. CROP-LEVEL TFP FOR SUGAR AND THE EASTERN UK COUNTIES

The previous section is a traditional analysis of aggregate TFP growth at the national level, which serves as a summary, but if the objective is to cast light on competitiveness, it leaves many questions unanswered. The Tornqvist-Theil index measures the average output, input, and TFP at any point in time but takes no account of dispersion or variance.[3] But there will be variance, between crops and other enterprises, among regions, and between more efficient and less efficient farms. Thus, many recent U.S. productivity studies are at the state level, and Conradie, Piesse, and Thirtle (2008) report TFPs for the Western Cape Province of South Africa at the magisterial district level. Also, nobody trades aggregate agricultural output. A country will tend to export those products in which

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[2]Refer back to the erratic increases in labor productivity referred to in Figure 7.3 and discussed in the text, which raised the issue of accuracy of the data.

[3]In this it is inferior to the Malmquist index, which separates technical change (the movement of the best-practice frontier) and efficiency change (the distance of observations from the best-practice frontier). This is important, as lack of movement of the frontier suggests that R&D is having no impact, whereas an increasing number of farms being left behind the frontier indicates that extension is not working well.

it has the most comparative advantage, and import, or at least not export, those in which it is not competitive. Also, the more efficient farms will be in the best position to export, perhaps even to other jurisdictions where the farms are less efficient. Thus, we now show that these variances matter and try to take them into account.

The United Kingdom does not have county-level data, and crop-specific TFPs normally cannot be constructed, as the allocation of some inputs (such as labor) among crops is usually not known. However, there are some exceptions, which serve to demonstrate the importance of variation across crops. First, we have data for sugar beets from Associated British Foods, from 1953 to 1992. The data cannot be feasibly extended to the present, but in Figure 7.7 we demonstrate how different crops can be. The figure shows the difference between the aggregate UK agricultural TFP, which grew at 1.88% per annum, and the sugar beet TFP, which grew at 3.46% per annum (Thirtle 1999).

There are also crop-specific data for sugar, potatoes, oilseed, rape (canola), wheat, and barley for the eastern counties of England, which cover most of the best arable land in the United Kingdom (Murphy 1998 and previous). These data are for 1970-97 only, as collection of suitable data was discontinued. Over this
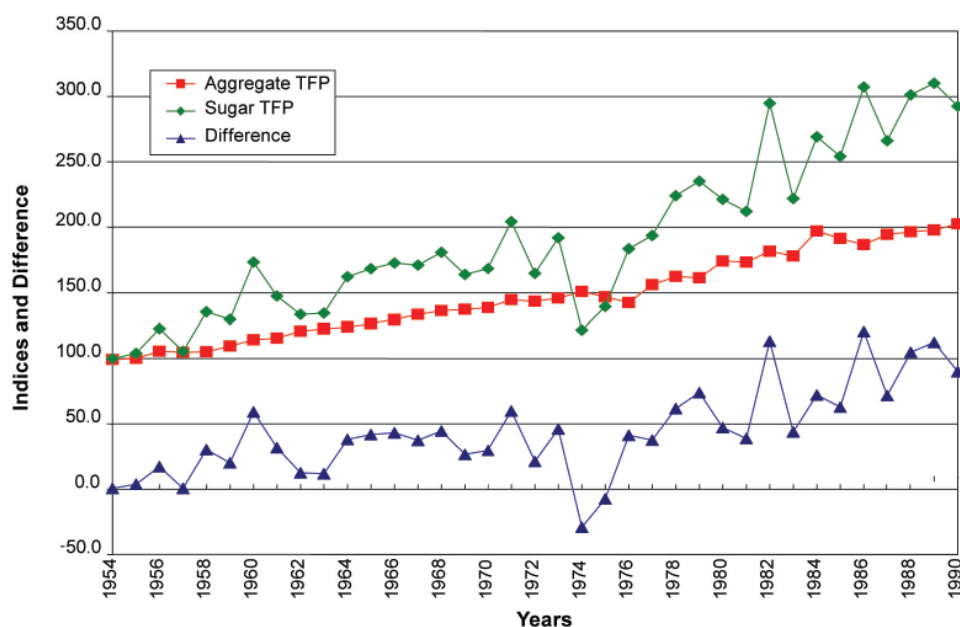

Figure 7.7. Difference between UK aggregate and sugar TFP
Sources: See Data References Appendix.

period, the eastern region accounted for an average of 56% of UK sugar production; 30% of winter wheat output; 26% of oilseed, rape, and potatoes; and 21% of spring barley. Thus, the TFP of these crops, which is a value-weighted aggregate of these indexes, is a reasonable sample of UK crop production. This can be compared to the UK aggregate TFP to see how productivity in crops has differed from that in horticulture and animal production. The more novel aspect of the study is that the sources of aggregate crop TFP can be decomposed into the innate productivity growth of the five crops and the effect of switching from crops with low TFP growth to those that have grown faster.

Figure 7.8 shows that after a poor start, the eastern region had far better TFP growth, at 2.87%, than the UK growth in aggregate, which was only 1.5% per annum. Unfortunately there is no way of comparing the starting levels, which were both set at 100, and this can also be crucial for comparison purposes. The eastern counties aggregate also conceals the very different growth rates across the crops. Oilseed rape grew at 5.77% per annum (but from a low base), sugar at 3.39%, wheat at 2.49%, barley at 1.89%, and potatoes at 1.19% (but from a high base). These comparisons are sufficient to expose the weakness of national aggregate TFPs for investigating relative competitiveness.

TFP growth results from the productivity growth of individual crops and from shifting from crops with low TFP growth to those with higher TFP growth rates. Baily, Bartlesman, and Haltiwanger (1996), and Baldwin (1996),
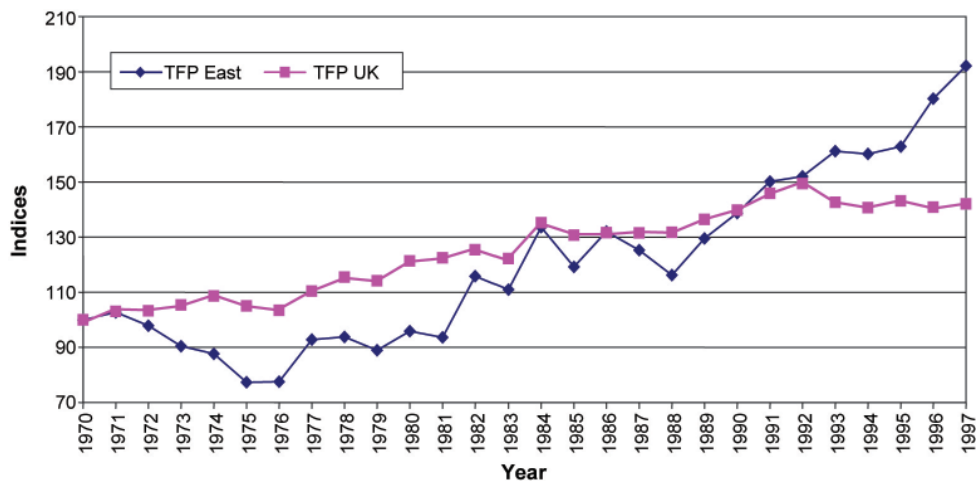

Figure 7.8. Eastern region and UK TFP indexes
Sources: See Data References Appendix.

use plant-level data for the industrial sector to analyze the effect that composition changes have on the translation from plant-level to aggregate productivity data. They show that growth in aggregate TFP can be the result of changes in output share among plants rather than within-plant increases in TFP.

Amadi, Piesse, and Thirtle (2004), following Baily, Bartlesman, and Haltiwanger (1996), calculate the contribution that each crop makes to the proportional annual change in the eastern region TFP, reflecting changes in the productivity of individual crops and the land area weighting, as shown in equation (1):

$$\frac{\Delta TFP_{Et}}{TFP_{Et-1}} = \frac{\sum_{i=1}^{5} \Phi_{t-1,i} \Delta TFP_{t,i}}{TFP_{Et-1}} + \frac{\sum_{i=1}^{5} \Delta \Phi_{t,i}(TFP_{t-1,i} - TFP_{Et-1})}{TFP_{Et-i}} + \frac{\sum_{i=1}^{5} \Delta \Phi_{t,i} \Delta TFP_{Et,i}}{TFP_i} \qquad (1)$$

where $\Phi_i = \frac{A_i}{\sum A_i}$ is the area share of the crop. Thus, regional TFP change is decomposed into three terms. The first term indicates how much of the productivity change reflects increases within individual crops and is the change in the TFP of crop i, relative to the regional TFP, with the area share held constant. The second and third terms, in which the area shares change, pick up the changes in productivity due to changes in crop mix. The second term is the product of the change in the area share and the difference between the crop TFP and the regional TFP, relative to the regional TFP value. This can be positive or negative depending on whether the average productivity crops are increasing or decreasing their area shares. The third term is the second crop mix effect, called the cross term by Baily et al. (1996), which is the product of the change in area and the change in the regional TFP, relative to the TFP for crop i. It is positive or negative depending on whether the crops that have positive productivity growth have increasing or decreasing area shares. Thus, each crop contributes not only through its own change in productivity but also because its area share is changing.

The contributions of each crop to overall productivity growth in the eastern region are reported in Table 7.7, where the first term in (1) corresponds to the productivity column. The second term is the input share column, and the cross-effects column corresponds to the third term in (1). The most interesting result, because it has not been previously measured, is shown in the last row, which attributes 77% of growth to the direct, within-crop TFP changes and 23% to crop switching. The input share effects exactly cancel out, leaving the cross term to capture this crop mix effect. The last column shows that wheat made the

Table 7.7. Direct and crop mix contributions of the crops to regional TFP growth, 1970-1995

Crop	Productivity	Input Share	Cross Term	Total	Total %
Sugar	17.92	-0.01	-1.73	16.17	17.55
Potatoes	0.51	-0.01	-0.08	0.42	0.46
Oil seed rape	0.46	0.10	33.94	34.50	37.45
Wheat	25.32	0.20	11.30	36.82	39.96
Barley	27.09	-0.28	-22.60	4.21	4.57
Total	71.31	0.00	20.83	92.13	100.00
Total %	77.39	0.00	22.61	100.00	

Sources: See Data References Appendix.

largest total contribution to the regional TFP, because of its dominance in the region, but oilseed rape, with less than 10% of the acreage, contributes almost as much, followed by sugar beets, while barley adds less than 5%, and potatoes approximately zero. The rest of the table shows the crop-level contributions, so the first row shows that sugar's contribution is entirely due to the direct effect of its rapid TFP growth. The area effect is small and negative, which is not surprising, as yields increased and the crop is subject to quantity quotas. The small contribution of potatoes is also composed of a positive, direct TFP effect and a small negative area effect, which is for the same reasons, as quotas were in force much of the time.

For oilseed rape, the minute area in 1970 results in a very small attribution to the direct effect of TFP change, with the large contribution being recorded under the crop mix effect, as the crop grew in importance to cover almost 10% of the area. For wheat, over two-thirds of the contribution is attributed to the direct TFP growth effect because of the large starting area, but as the area expanded, there is also a crop-switching contribution. Barley shows that the decomposition has to be carefully interpreted. Because of the large area share in 1970 and reasonable TFP growth, barley is recorded as making the largest direct contribution to TFP, which is somewhat counterintuitive, but the effect of the area decline is almost as large, leaving a very small total contribution.

7. INTERNATIONAL COMPARISONS OF PRODUCTIVITY

International productivity comparisons that include the United Kingdom and the United States resulted from a USDA project and began with an analysis by Thirtle et al. (1995). The analysis compared the agricultural TFPs of the 10 countries that then comprised the European Community with the TFP of the

United States from 1973 to 1989. At the beginning of the period, with the average of the 10 EC counties set at 100, the range was from 141 for the Netherlands and 135 for Belgium down to 86 for Greece and 81 for Italy. The United States was placed third in this ranking, with a TFP of 124, and the United Kingdom was fifth, with 110. By the end of the period, the Netherlands still led, followed by the United States, and the United Kingdom had fallen to sixth in the spatial ranking. This was because the UK TFP had grown at only 1.7% per annum, as compared with the EC-10 average of 2.1% per annum, which was also the U.S. growth rate. The TFP changes were explained by public R&D expenditures, private patents, extension expenditures, education, spillovers of public R&D among national jurisdictions, and the weather. The main finding was that the average spillover effects were bigger than the average of the direct effects of national agricultural research systems within the countries of origin.

Schimmelpfennig and Thirtle (1999) updated this work to 1993 and with the extra years of data found that the United States was the leading country in TFP by 1993, as illustrated in Figure 7.9. Advances in the measurement of convergence showed that the United States and the leading northern European countries were converging in TFP to a high-level growth club, while the southern European countries were falling behind and themselves converging on a low-growth equilibrium.
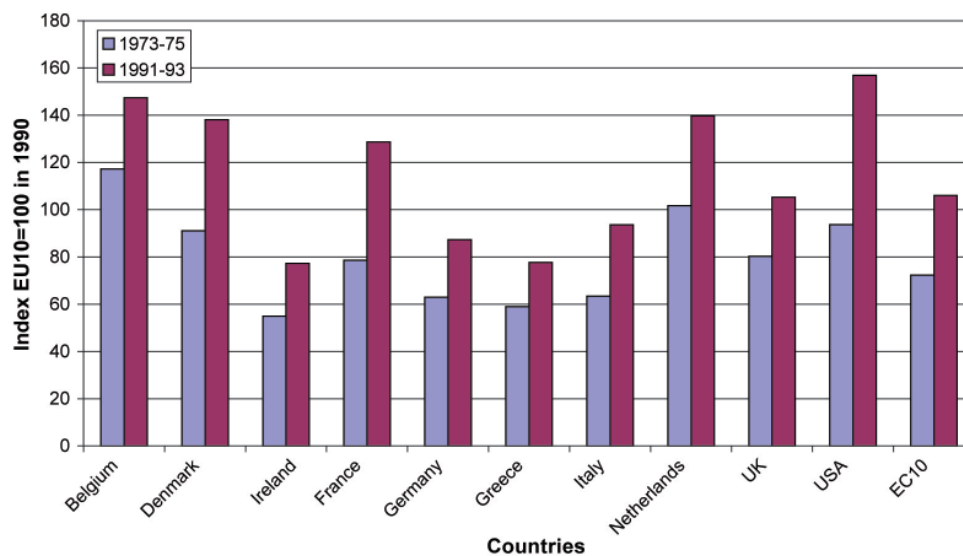

Figure 7.9. Comparing TFP in the United States and the European Community 10
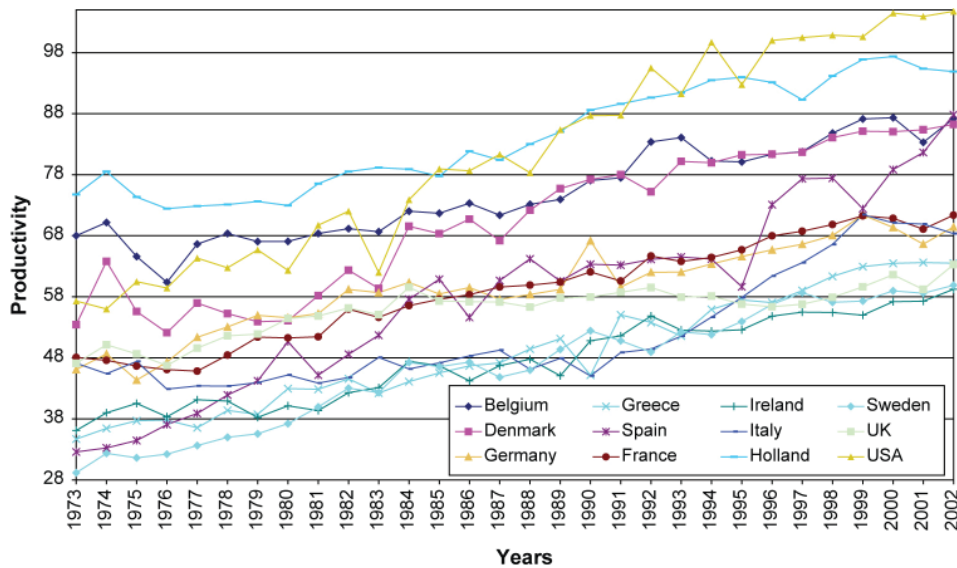*Sources*: See Data References Appendix.

Figure 7.10. TFPs for the EU countries, 1973-2002
Sources: See Data References Appendix.

The most recent update is from Eldon Ball of the USDA and is associated with the competitiveness study of Ball, Butalt, and Mendosa (2004). Figure 7.10, which was constructed from Ball's data, shows that when the TFP comparison is updated to 2002, the United States retains its lead while the United Kingdom has declined to the same level as Sweden, Ireland, and Greece. The lengthy period of stagnation in the United Kingdom is quite clear in Figure 7.10.

A report to DEFRA on the impact on UK agriculture of increasing agricultural productivity in EU acceding countries (Thirtle et al. 2004b) included farm-level data. These data were included because the aggregate results for the study showed that even the most advanced new member states were on average not competitive with the United Kingdom. However, on the basis of the farm-level data, we argued that the top end of the distribution in the new member states would be more efficient than the bottom end of the distribution of UK farms, as shown in Figure 7.11. Foreign-owned, large-scale, advanced technology enterprises in countries like Poland and Hungary had very little in common with those countries' average farms and were almost certainly far more efficient than the tail end of small UK farms, which were struggling. This should be kept in mind when reviewing the work on international comparisons.
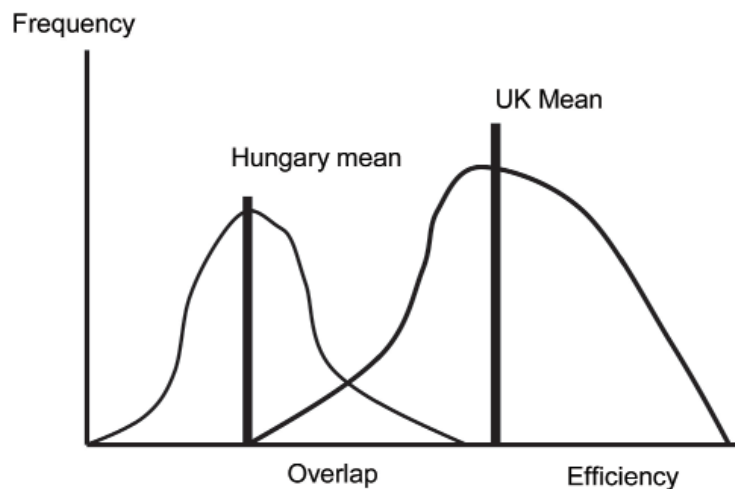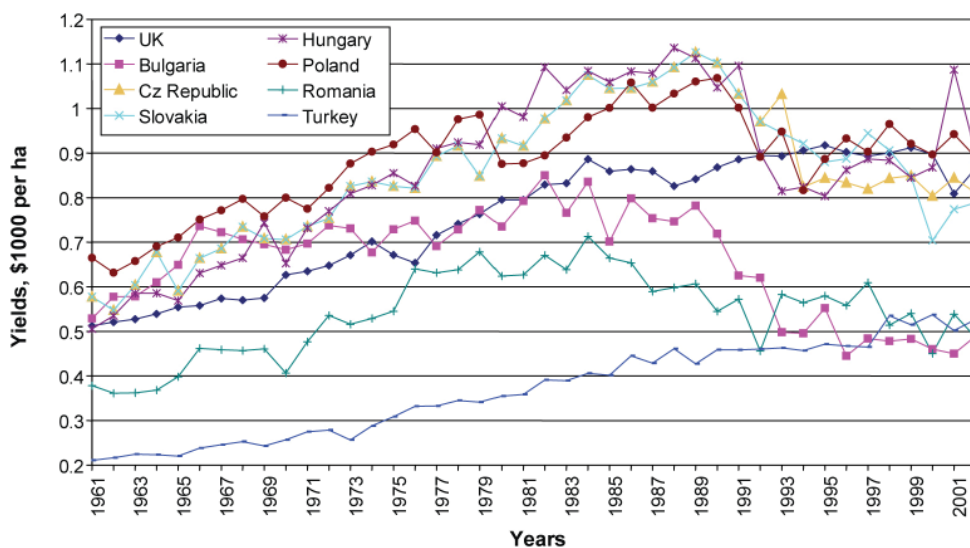
Figure 7.11. Distribution of UK and Hungarian farms

Figure 7.12. Yields, United Kingdom and potential European Union entrants
Sources: See Data References Appendix.

The national aggregate comparisons in the DEFRA report by Thirtle et al. (2004a) used Food and Agriculture Organization (FAO 2005) data to compare aggregate yield in value terms, labor productivity, and TFP. Yields for the United Kingdom and the new member states are in Figure 7.12, which shows that the UK yields were actually considerably lower than those for Poland, Hungary, and

the former Czechoslovakia, until these countries suffered setbacks during the transition in the early 1990s. By 2002, yields in the United Kingdom, Poland, Hungary, the Czech Republic and Slovakia were all grouped at around $800-$900 per hectare, while Bulgaria, Romania, and Turkey were only at around $500 per hectare. It is apparent that aggregate yield values generally declined in the 1990s, with Turkey the only exception.

Yields are of great interest to agricultural scientists, but as Hayami and Ruttan's (1985) comparisons of Japan and the United States showed, maximizing yield is of major interest only to countries where land is scarce. The majority of productivity growth in the advanced countries comes from shedding labor. This is reflected in Figure 7.13, which shows the value of annual output per agricultural worker for the full sample of incumbent, new, and potential EU states, in $1,000 U.S. purchasing power parity, 1990 base. The leading country in this dimension is Belgium/Luxembourg, which by 2002 had output per worker of
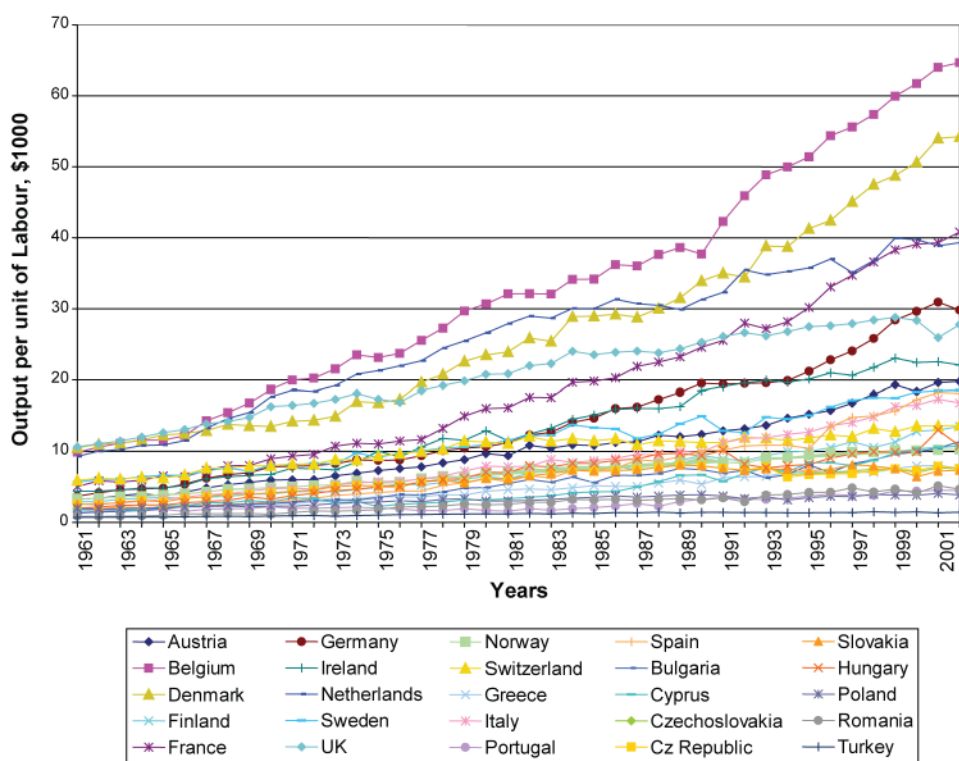

Figure 7.13. Labor productivity for the European Union and entrants
Sources: See Data References Appendix.

$65,000, followed by Denmark, at $54,000. The UK level at $28,000 is just over 50% that of the Danes, but this is still almost triple the levels of the two leading entrants, Bulgaria and Hungary, which are about $11,000 per worker. Notice too, that the growth rates of the leading countries have, if anything, increased, but the UK growth rate slows after 1984. Since labor reduction dominates TFP growth, this turning point will come up again in the TFP section.

Figure 7.14 shows the United Kingdom and the new entrants only, as the larger scale allowed by the smaller dispersion makes the differences clearer. Now it is very clear that the United Kingdom may be well behind the EU leaders, but it is still in a different league from the potential entrants. In turn, even Poland, which is the worst of the Central and Eastern European countries, has output of almost $3,900 per worker, whereas Turkey is still in the emerging economy range at just over $1,400 per worker.

Since the lack of prices and hence factor shares precluded the Tornqvist-Theil approach, the methodology for TFP measurement was to generate the Malmquist index using both data envelopment analysis (DEA) and stochastic frontier estimation. The resulting indexes are shown in Figure 7.15 for the full sample, and the
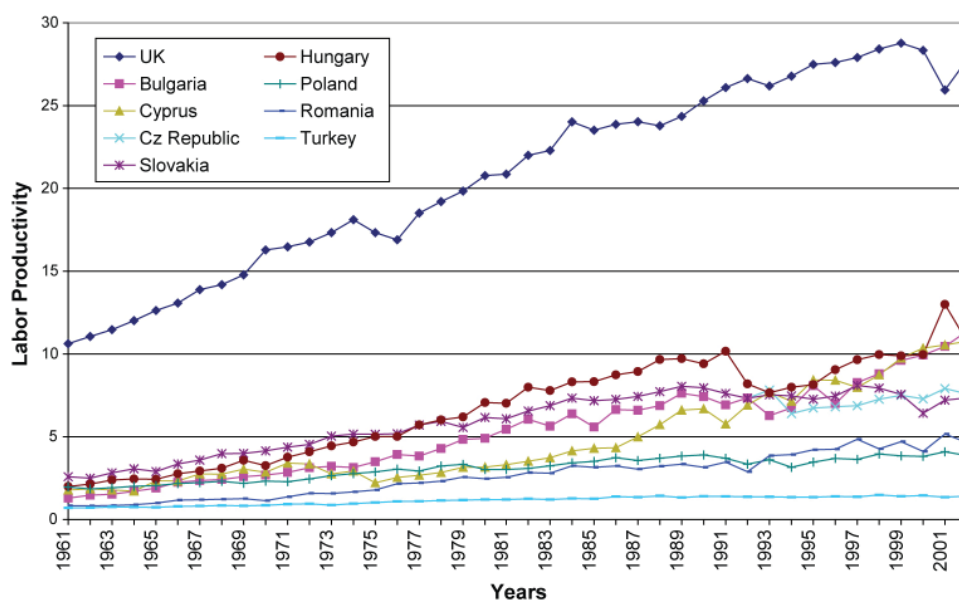

Figure 7.14. Labor productivity in the United Kingdom and potential European Union entrants
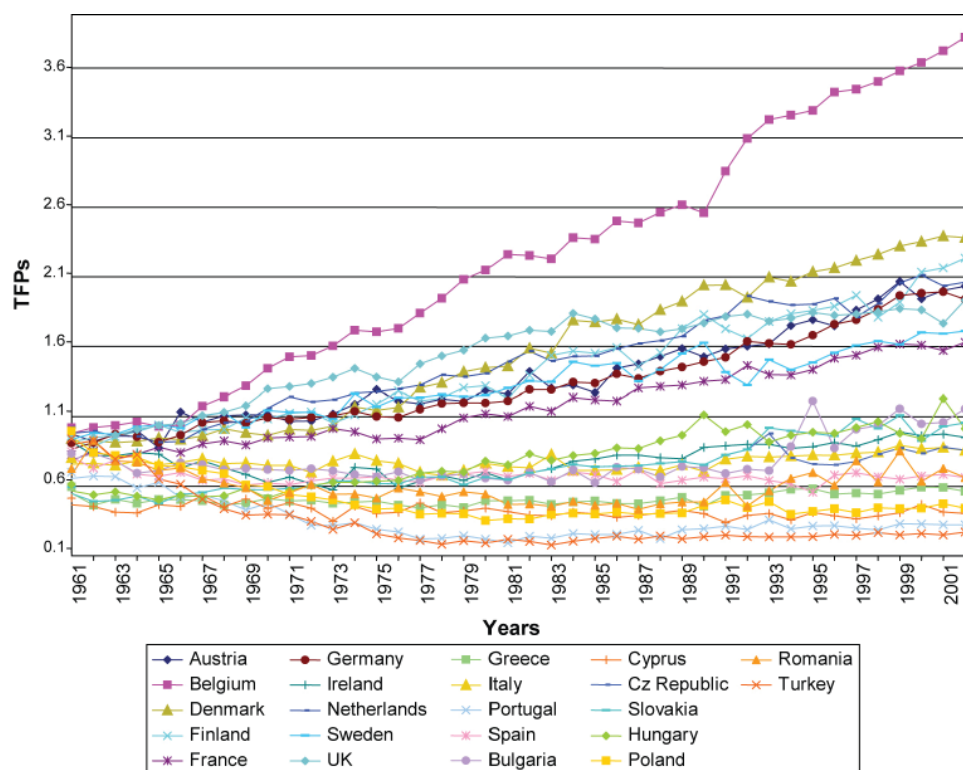*Sources:* See Data References Appendix.

Figure 7.15. Malmquist TFP for the European Union and entrants
Sources: See Data References Appendix.

results are quite clear.[4] There are two distinct groups, with the northwestern EU countries making up the successful upper group and the rest confined to the low TFP growth group. The only exception to this regional division is the Republic of Ireland, which is in the low-growth group, finishing behind Bulgaria, Slovakia, and Hungary, all of which have final values of around 1.1. These are followed by Italy and the Czech Republic, then Romania, Spain, Greece, and Poland, which are still ahead of Cyprus and Portugal, with Turkey consistently last.

Do any of the new entrants seem likely to catch up with the northwest EU group in the foreseeable future? The gap between the leading accession countries (Bulgaria, Czech Republic, Slovakia, and Hungary at 1.1) in 2002 and the last country in the northwest EU group is 0.5. Now compare this with the best progress made by any of the lower group. Hungary has gone from 0.56 to 1.01,

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[4]If Belgium, which has the highest levels and growth rates, is excluded, the outcome is clearer because of the larger scale on the graph.

which is a gain of 0.45 in 42 years. Thus, unless there are organizational changes that give massive growth, it seems unlikely that the agricultural sectors of the potential entrants could achieve the TFP levels of the northwest EU group in less than 40 years, or by about 2050. A slightly more sophisticated calculation can be made by looking at a series for each of these countries determining any discernable trend during the last few years and using just these years to estimate growth projections. The results of this exercise are in Table 7.8.

The potential entrant that is in the leading group and has the best growth rate is Hungary, which is growing 2.2% faster than the United Kingdom on these projections. At that differential growth rate, Hungary should catch up in 36 years. Of course, this is a matter of the whole sector catching up, since in this analysis we can only look at all outputs relative to all inputs. This is useful but hardly an adequate answer, especially since the countries in central and eastern Europe have dualistic agricultural systems, to differing extents. If a country has a backward sector of small peasant farmers and co-operatives or formerly state-owned farms that are larger and better endowed with resources, then we need to be able to separate the better enterprises and compare them with UK or U.S. farms. That is why the previous section considered farm-level data.

8. EXPLAINING CHANGES IN UK TFP GROWTH: CAUSES OF THE DECLINE

The UK track record on productivity growth is sufficiently poor that it is worth considering the causes to avoid making the same mistakes. The causes of the decline can be divided into two types: some are an illusion, caused by better measurement of the same reality, while others actually result from real changes.

Table 7.8. TFP growth projections

Country	Years	TFP Growth Rate (%)
United Kingdom	1984-2002	0.39
Bulgaria	1997-2002	1.85
Cyprus	1994-2002	1.67
Czech Republic	1995-2002	2.31
Hungary	1993-1998	2.62
Poland	1994-2001	1.90
Romania	1994-2001	1.25
Slovakia	1993-1999	1.39
Turkey	1995-2002	0.47

Sources: See Data References Appendix.

It is possible that there has not been any decline but only if less conventional measures are used. Thirtle et al. (2004a) reports two cases in which the decline practically disappears, and we begin with these. Then, there are two reasons why the measurements have changed, one due to better data and the other to the increasing appropriability of biological innovations. The main causes of the real decline are then covered, which are the lack of investment in UK agriculture, cuts in public R&D, the effect this had on private sector patents, and the slowing of the growth of farm size. Concerning the effect of the demise of the public extension service in 1988, it is only possible to speculate on the effect. Finally, there are four other possible causes, two that are external to the sector, which are unlikely to have had large effects.

1. Correction of the TFP calculation when technological change is biased. The calculation of TFP assumes that technological change is Hicks neutral (that is, it saves all the inputs in the same proportion as they are being used) and imposes this condition. It has now been shown that when technical change is actually biased, as it is in UK agriculture, this can lead to serious errors in measurement, which get worse over time. Thirtle et al. (2003) and Bailey, Irz, and Balcombe (2004) show that if the factor shares used in aggregation are adjusted to allow for biased technical change, the resulting TFP index shows almost no sign of decline after 1984. Although a paper on this subject won the best contributed paper prize at the meetings of the International Association of Agricultural Economists in 2000, this correction is certainly not yet accepted as conventional wisdom.

2. A social TFP adjusted for environmental externalities. Conventional measures of TFP do not take into account inputs and outputs that are externalities in the production process. Hence these measures do not account for the potentially polluting substances that are produced by agriculture alongside food and other products. These substances include nitrates, pesticides, and greenhouse and other gases, and their emission can potentially contribute to biodiversity loss and climate change, among other negative environmental impacts.

Total social factor productivity is estimated using the conventional productivity measures calculated by Thirtle et al. (2004a) and incorporating emissions of various polluting gases from UK agriculture for the period 1970 to 1999. This new measure showed that total social factor productivity has grown at 1.7% per annum since 1984, as compared with 0.26% for the conventional TFP. This reflects a decline in emissions of polluting gases, as farms have switched fuel

types over the period, and since the 1990s, because of the ban on field burning of crop residues.

This is a very sensible outcome, in view of the fact that the reforms of public R&D in the 1980s and 1990s made productivity-enhancing research the responsibility of the industry. Public money was redirected toward the production of public goods, which meant lessening pollution, and increasing countryside stewardship, animal health and welfare, and food safety. Thus, it is hardly surprising that this is where the growth is.

3. Detailed data and quality change. Why would the new DEFRA data give lower growth of TFP than the old data? The quality adjustment reason raised earlier harks back to the important debate that centered on Jorgenson and Griliches's (1967) criticism of Dennison's (1962) growth accounting for the U.S. economy. Dennison showed substantial productivity growth, but this was the residual, not accounted for by inputs, which Jorgenson and Griliches dismissed as measurement error. They argued that if all outputs and inputs were included and correctly measured in efficiency units, thus allowing for quality change, TFP growth should be exactly zero, as inputs must explain outputs. This rests on the notion that all technical change is embodied in inputs, and Jorgenson and Griliches did back down somewhat in later papers. For example, in agriculture, there can be disembodied technical change, due to differences in managerial ability. A better farmer can produce more with exactly the same inputs, by planting, fertilizing, weeding, and harvesting at the right time.

The Jorgenson and Griliches argument is relevant here, since the old MAFF data were far cruder than the new DEFRA data, so there must be a tendency for less of the output to be properly accounted for. The results reported by Barnes (2002) support this supposition. Barnes constructed a TFP directly from the Central Statistical Organization data published in the Annual Abstract of Statistics. This gives very little detail, and he used four output categories and eight inputs. These data were much less detailed than those used by MAFF or Amadi (2000) and the result is that Barnes's TFP fails to show any kind of decline in the 1990s. The annual growth rate of TFP from 1972 to 1995 is 3.25%, which is huge relative to the results based on the old MAFF index, let alone the new DEFRA results.

4. The switch from public to private R&D. It is possible to build on the work of Jorgenson and Griliches (1967) by asking what an agricultural TFP index measures. Most of what it measures are the effects of the technology

produced by the public sector and made available almost free of charge. This "public good" is a gift to the private sector input suppliers and for that reason does not get included in attempts at quality adjustment of inputs. This is why Griliches (1964) included public R&D in the production function, but neither he nor Evenson (1967) included private R&D. Thus, as appropriability has improved and the private sector has increased its share of technology generation, now outspending the public sector, the improved technology is more likely to be accounted for in the quality-adjusted input series, which should decline less or grow more rapidly. Thus, measured TFP growth should decline continually as this process advances. If the public sector withdrew completely and quality adjustment of inputs was accurate, Jorgenson and Griliches's claims would prove almost to be true.

5. Lack of investment in UK agriculture. The structural break in UK TFP comes in the mid-1980s, immediately after the peak in public R&D expenditure in 1982. Since the peak effect comes with a lag of 12 or more years and the initial effects tend to be very small or even non-existent (Thirtle, Piesse, and Schimmelpfennig 2008), it seems likely that other real causes need to be examined. A leading candidate, at least according to the agricultural scientists, is the lack of profitability of the sector, which by the mid-1980s was reflected in a lack of investment. This suggestion is worthy of examination, as it must have some credence.

6. Reduction and retargeting of public agricultural R&D. The next three reasons are quantified and can be shown to account for the decline. Thirtle et al. (2004a) showed that TFP growth has actually fallen from 1.68% per annum before 1984 to 0.26% thereafter, and thus there is a reduction of 1.42% to account for. Figure 7.16 shows that public agricultural R&D grew at 6% per annum until 1982, when growth ceased. Then, the fall in TFP follows after two years, which is perhaps too soon to be feasible. The elasticity of 0.13 for R&D reported in Thirtle et al. (2004a) allows a rough calculation of the impact of the R&D cuts on TFP. With R&D growing at 6% per annum this should have accounted for 0.8% per annum of TFP growth, which leaves a further 0.62% to be accounted for.

This section has suggested that TFP growth may also be reduced by the following: using the Tornqvist-Theil index and including the animal capital stocks, but this caused only small reductions; using better data combined with quality adjustment; measurement errors combined with the switch toward private R&D; and ignoring the biases in technological change. The rest of this section adds other possible explanations that could account for the remaining 0.62% per annum of
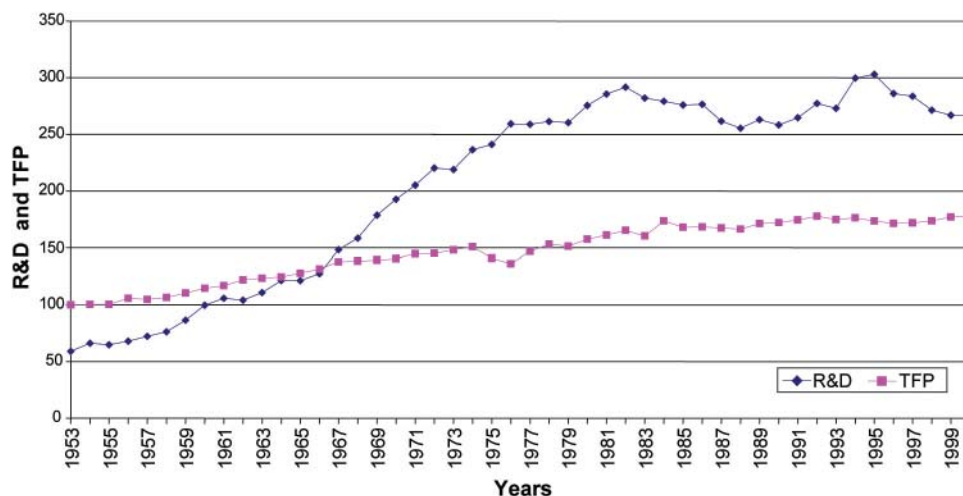
Figure 7.16. Public R&D and TFP
Sources: See Data References Appendix.

lost growth. The first follows from the analysis of the effects of public R&D in the previous section. The Office of Science and Technology (1995) subtitled its *Technology Foresight* publication *Progress through Partnership*. The argument was that technological goals should be achieved through public and private sector collaboration, in which the public institutions produce basic scientific and public interest research and the private sector is responsible for product development, and near-market and productivity-enhancing research. The public sector should provide the scientific base for the applied research and development of the private institutions. The relationship between public and private R&D has been studied, and the usual suggestion is that the two activities are complements. Thus, the reduction in public R&D is highly likely to have reduced private R&D, and this effect also needs to be estimated and taken into account.

In sum, there is strong evidence of market failure and the need for continued and increased public funding of agricultural research. Yet critics of the reforms of agricultural research over the past 25 years have noted that neither the word agriculture nor food appears in the title of the BBSRC, and that DEFRA is no longer involved in promoting more efficient production of food on British farms. This, together with the reluctance of the private sector to fill the gap, makes it difficult to disagree with Spedding's (1984) assertion that publicly funded agricultural research in the United Kingdom no longer exists. The soundness of this situation is unclear. One might ask, for example, on whom will the now very

important food industry rely for research on the commodities that constitute its raw materials? The government needs to reconsider policies to better ensure sensible allocation of resources between the public and private sectors. Needless to say, there may be lessons here for the many other governments, such as those of Australia, New Zealand, the Netherlands, and the United States, that have similarly sought to reduce public spending, to shift any remaining funds toward areas in which there is clear evidence of market failure, and to enact legislation promoting greater private funding of agricultural research (Alston, Pardey, and Smith 1999). Yet, the complexity and unequal distribution of the reallocations in the United Kingdom (Thirtle, Palladino, and Piesse 1997) should warn against superficial comparisons of the experience in countries in which agricultural research has historically been organized very differently.

7. **Private sector patents.** The evidence on recent private sector activity is limited, but there are good data on patents pertaining to agriculture from the Yale Technology Concordance. The first column of Table 7.9 reports the total number of patents granted by the United Kingdom to all the major foreign applicants from 1969 to 1995. The number increases until 1978, when it reaches a peak of 923, before falling to an all-time low of 449 in 1988 and then recovering to its earlier levels by 1995.

The lower numbers coincide with the decline in public R&D, but the patent series declines first, suggesting that the United Kingdom was becoming a less attractive market before the R&D cuts began. The behavior of foreign patent applicants is important, but the key point here is the relationship between UK R&D and UK patents, as the UK patent series is quite different. From 1978 to 1983 the level of UK patents is consistently high, at well over 300. Then, from 1984 onward, the number declines, falling to 70 in 1988, or barely 20% of what it was before the cuts began. This relationship is shown in Figure 7.17. Regressing patents on R&D, with a one-period lag (so that R&D is predetermined and hence weakly exogenous) shows that a 1% reduction in R&D leads to a 1.62% reduction in domestic patents.[5] This suggests that public R&D and domestic patents are complements rather than substitutes, and when the growth of public R&D was cut from 6% per annum to zero, the effect on private activity would have been a reduction of 9.6% (6*1.6). The elasticity of TFP with respect to patents is about 0.07 (from Thirtle et al. 2004a), so this would have reduced TFP

[5]Note that the patents are both private and public, so some of the decline is due to less public sector activity.

Table 7.9. Patents registered in the United Kingdom, by applicant country

Year	Total	All Foreign	UK	U.S.	Germany	Japan	France	Holland	Switzer -land	Italy	GB/ Foreign
1969	542	310	232	115	61	11	31	40	12	5	0.748
1970	883	533	350	176	95	23	40	95	20	5	0.657
1971	827	499	328	157	108	16	56	51	33	9	0.657
1972	816	518	298	170	118	29	37	57	25	12	0.575
1973	716	441	275	150	101	27	39	27	22	11	0.624
1974	664	405	259	126	82	22	38	50	16	11	0.640
1975	806	513	293	177	107	22	43	52	24	9	0.571
1976	780	488	292	148	109	31	64	46	18	5	0.598
1977	769	515	254	147	109	28	39	87	18	9	0.493
1978	923	589	334	169	129	42	40	87	22	6	0.567
1979	845	502	343	153	118	44	38	70	20	7	0.684
1980	767	421	345	138	107	44	36	55	18	9	0.820
1981	688	348	341	123	96	44	34	42	16	9	0.979
1982	610	281	329	108	85	43	32	30	15	10	1.169
1983	532	222	310	93	74	41	29	20	13	10	1.400
1984	515	259	257	84	73	50	29	19	12	10	0.991
1985	499	293	206	75	72	59	30	17	12	10	0.702
1986	482	324	158	67	71	67	30	16	11	11	0.486
1987	465	353	112	59	70	74	31	14	11	11	0.318
1988	449	379	70	51	68	81	31	13	10	11	0.185
1989	476	397	79	65	79	81	35	15	10	13	0.199
1990	658	542	116	105	120	107	52	23	13	20	0.214
1991	530	431	99	96	104	81	44	20	10	17	0.229
1992	557	448	109	114	118	80	49	22	10	19	0.244
1993	584	463	120	132	133	79	54	25	10	22	0.260
1994	733	622	111	185	108	102	50	28	11	23	0.179
1995	883	781	102	237	83	124	46	31	12	25	0.131
Total	**18000**	**11877**	**6122**	3420	2598	1452	1076	1051	426	321	

Sources: See Data References Appendix.

by a further 0.67% per annum. This estimate is a bit crude, but it says that the total effect on TFP of the cut in UK public R&D was 1.47%. Thus, the public R&D cuts and their effects on private activity are alone sufficient to explain the 1.42% reduction in TFP growth. However, there are other possible impacts that need to be considered.

Table 7.9 also suggests that the relationship between UK R&D and patents is negatively related to foreign patents. By 1989, when there are only 79 UK
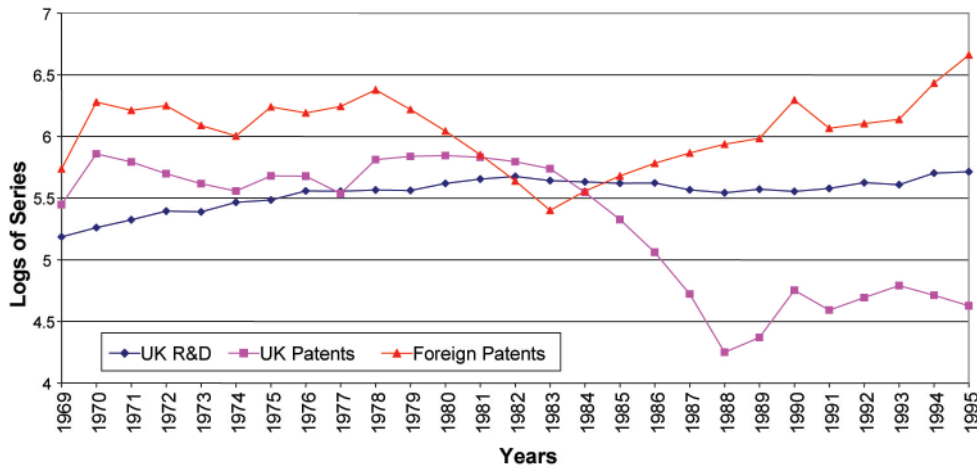
Figure 7.17. Public R&D, UK patents, and foreign patents
Sources: See Data References Appendix.

patents, this figure is matched by the Germans and exceeded by the Japanese, which is quite remarkable. The last column of Table 7.9 shows that whereas UK patents exceeded all foreign patents in 1982 and 1983, by 1995 the United Kingdom was only registering 13% of the number of foreign patents. Thus, it looks as if the demise in UK activity has led to a vast increase in the relative importance of foreign multinational company activity. This is also a result that seems not to have been noted before. It suggests that cutting back the UK R&D effort may well lead to a greater level of foreign technology entering UK agriculture. Imported private sector technology is a substitute for national public and private R&D and may be a partial cure for slow TFP growth. The figures show that from 1983, the result of a 1% reduction in UK patents is a 0.54% increase in foreign patents registered in the United Kingdom. If foreign patents have the same impact on TFP as domestic patents, a further effect of the public R&D cuts would be to increase TFP by 0.22% per annum because of the increase in foreign activity.

8. Farm size. Thirtle et al. (2004a) showed that growth in farm size also affected TFP growth, but the coefficients on the two policy variables were very small indeed. Figure 7.18 shows that farm size practically ceased growing in the 1990s, when the rate fell from 1.0% per annum to 0.1%. The elasticity of 0.21 from Thirtle et al. (2004a) suggests that this cut of 0.9% could have reduced TFP growth by 0.19%. Set this against the extra 0.22% due to foreign activity and the numbers add up almost perfectly to explain the decrease in TFP growth.
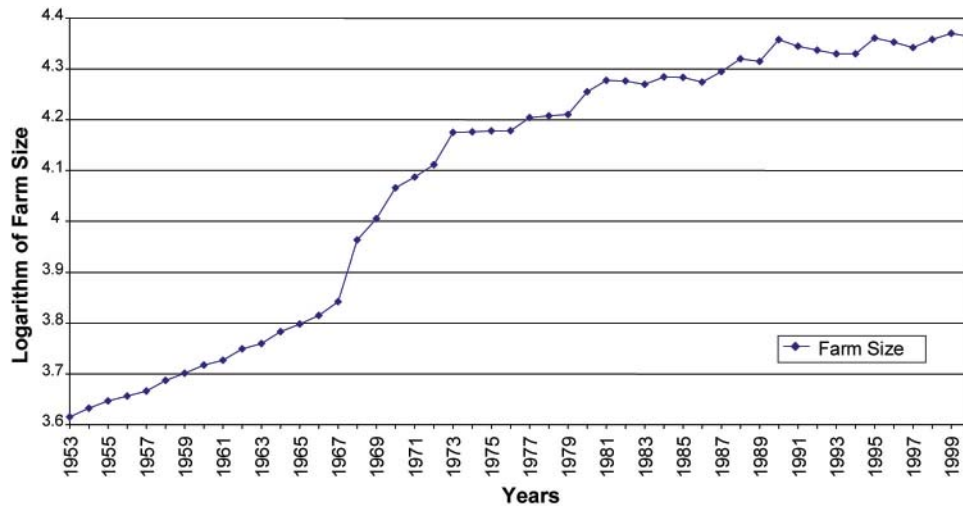
Figure 7.18. Farm size (log scale)
Sources: See Data References Appendix.

9. Extension. Extension expenditures could not be included in this section, because there are no data after 1988, when free public extension services ceased, but it is possible to speculate as to the effects. The conventional wisdom (Thirtle, Piesse, and Turk 1996) suggests that R&D creates technology that moves the frontier forward, while extension spreads the knowledge to farmers to ensure that they adopt the new techniques and stay close to the efficiency frontier. Hadley (2006) used farm-level data to study efficiency change and showed positive technical change but considerable decreases in efficiency as farms fail to keep up with the advancing frontier. These results suggest that the demise of the public extension service has also reduced TFP growth.

10. The long-run growth path. There is reason to believe that past levels of growth cannot be maintained. Jones (1999), in a paper first presented at the Allied Social Sciences annual conference in Chicago in 1998 under the title "The Upcoming Slowdown in US Economic Growth" (Jones 1997), pointed out that the U.S. growth rate from the 1950s cannot be maintained. Rapid growth has been driven by increases in educational levels, increases in research intensities, and increased openness of the world economy. These are all one-off changes, in the sense that it will not be possible to continue doubling the proportion of the population attending universities, which has reached about half, or doubling research intensities, which are already over 20% of sales for high-tech industries

like pharmaceuticals. Neither can the world economy be opened up a second time. Thus, Jones showed that the U.S. economy is far from its long-run balanced growth path. His calculations showed that 35% of U.S. growth is attributable to the rise in education levels, 40% to increases in research intensity, and only 25% to the components of long-run growth. Thus, at some stage in the relatively near future, growth must fall from close to 3% per annum to less than 1%.

The same is true of productivity growth in agriculture. Education levels need improving but cannot grow forever, and the multinational input companies must be getting close to the maximum possible research intensities, so TFP growth must slow down in the long run.

11. Asset fixity. There are three other possible causes, which are worthy of mention. One is the well-known proposition that when farmers reduce output, costs will not fall as much as they rose during expansion. Asset fixity and the lack of perfect secondary markets for capital items account for this, and, similarly, TFP growth may be more easily achieved when output is expanding, so that capital is fully utilized and purchased only when needed. When output is contracting, capital goods are likely to be underutilized and the stock can only be reduced at the rate of depreciation. Output data for a sample of countries is needed to test this proposition, but it is obvious from Figure 7.2 that output ceased growing in the United Kingdom in 1984.

12. Convergence. The remaining two possible causes seem to be unlikely. First, regressions to explain TFP in panel data usually include starting values, since catching up tends to be easier than leading. This can hardly apply to the United Kingdom, which has not been a leader in productivity terms for a very long time, and the current leading countries are doing far better.

13. Ozone pollution. Finally, industrial pollution affects yields. There is now substantial evidence that low-level ozone pollution reduces cereal yields, and we suspect that ozone has contributed to the decline in yields in other crops. The plant biologists have conducted controlled experiments on cereal yields, which show that low-level ozone pollution levels that are not damaging to human health severely affect crop yields. Experiments in the United Kingdom show that ozone dispersion is wide, so most areas are affected, and yields are reduced. However, although the plant breeders have not recognized the problem, their trial plots are in affected areas, and they have inadvertently limited the damage by selecting ozone-tolerant varieties. The evidence to date (Shankar and Neeliah 2005; Kaliakatsou, Thirtle, and Bell forthcoming) suggests that the yield losses due to ozone are no

more than about 2%-3%. Also, the United Kingdom is no more affected than other EU countries, so it is unlikely that this can be the cause of its relatively poor performance in terms of yield growth, which was noted earlier.

9. CONCLUSION

This chapter began with a brief review of policy changes in UK agriculture, changes that are used later in explaining technical and efficiency change at the farm level. The history of yield changes in the United Kingdom shows that the notion of an agricultural revolution from about 1750 is too simplistic. There were more prior changes of perhaps equal consequence. What is beyond doubt is that the massive increase in the growth rate of yields only occurs with the application of modern science after WWII. However, in the United Kingdom the increase in yield growths from the historical rate of around 0.2% per annum to 2% per annum lasted less than half a century. Since 1996, cereal yield growth is actually lower than between 1885 to 1945.

In the period beginning in 1953, for which good data are available, yields, output, and TFP grew at unprecedented respective rates of 2.08%, 1.87%, and 1.67% until 1984. Since 1984, output and yields have fallen slightly, and TFP grew at an average of only 0.3% until 1996. Since then, TFP has increased to 1.2% growth per annum. Only labor productivity has continued to grow really rapidly, at 3.86% per annum until 2000, and at 6.4% since that date. However, we question this last figure as there is no substitution of machinery, equipment, and buildings. Indeed, all the capital inputs have declined since the mid-1990s following reported low levels of investment from the mid-1980s. These declines are thought to be a cause of the United Kingdom's recent poor productivity growth, so the big jump in labor productivity suggests possible undercounting of workers from the new EU member states and elsewhere.

The aggregate TFP suffers from the limitation of ignoring variance across regions, crops, and farms, which limits its usefulness for comparisons of competitiveness. Thus, the next step is to consider crop- and region-specific TFPs for the eastern counties of England, which is the prime arable area. The TFP for sugar grew considerably faster than the aggregate UK index, and the eastern counties' aggregate index for sugar, oilseed rape, wheat, barley, and potatoes grew at 2.87% per annum as compared with 1.5% per annum for the UK average for the same period. Crop-specific TFP growth rates varied from 5.8% for oilseed rape to 1.19% for potatoes.

The farm-level studies of the United Kingdom decompose the rates of technical change and efficiency change, which both vary with farm type. They show that while there has been substantial technical progress, average farm-level efficiencies have fallen, which means that the laggards are not keeping up and will drag down average productivity. This suggests that the demise of free extension advice may be a factor in poor productivity growth. The analysis at the farm level also contributes to our understanding of TFP change by measuring the effects of policy changes and exogenous shocks such as animal disease epidemics, like BSE, and by showing the variance in efficiency within farm types. The variance in efficiency across farms needs to be kept in mind when comparing aggregate TFP levels as a guide to competitiveness.

Productivity comparisons between the EC-10 countries and the United States show that the United States does tend to have higher productivity than its nearest European rivals. However, Section 8 shows that there are other factors involved in competitiveness. Productivity comparisons across the EU countries, intended to assess the impact on UK agriculture at the accession of new member states, show that UK yields were actually lower than those of the leading new members such as Hungary, Poland, and the former Czechoslovakia. However, labor productivity and TFP was much higher for the United Kingdom and other incumbent EU member states. A rough estimate of the time it will take for fast-growing Hungary to catch the United Kingdom in TFP is 36 years.

These aggregates conceal the fact that the best producers in these countries are way above the national averages and are more productive than the bottom end of the UK farm distribution. Particularly, agriculture in countries like Hungary is dualistic, with some large, modern, efficient farms using the latest technology, while the majority of small-holding farms are backward and drag the average way down. Thus, aggregate TFP and even the competitiveness study reported in this paper are of dubious value in predicting the exporting ability of some emergent European countries.

Even so, the competitiveness of the United States, taking input prices and exchange rates into account, as well as TFP, is normally better on average than even the leading EU countries. The exceptions are brief periods in the early 1970s and mid-1980s, when Denmark, Belgium, and Germany had a slight aggregate price advantage.

The last section of the chapter considers the reasons why the UK's TFP performance has been so poor. Clearly, the United Kingdom dropped from

one of the better EU countries in TFP terms to sharing last place with Sweden, until the recent accession of new members that have far lower TFP levels. The United Kingdom's failure in this area has been well recorded and should serve as a warning that the agricultural sector does need public support, or some viable alternative means of producing public goods to support farmers.

APPENDIX A: DATA SOURCES

Figure 7.1: Crop Yields

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1966-71: FAO Statistical Database. 2005. On CD-ROM, FAO, Rome.

1971-1987: Burrell, A., B. Hill, and J. Medland. 1990. *Agrifacts: A Handbook of UK and EEC Agricultural and Food Statistics.* London: Harvester/Wheatsheaf.

1987-2008: DEFRA. Various editions and online. *Agriculture in the United Kingdom.* London: Her Majesty's Stationery Office.

Table 7.4 and Figure 7.2: Output, Input, TFP, Yield, and Labor Productivity Indexes

1953-2000: Thirtle, C., L. Lin, J. Holding, and L. Jenkins. 2004. "Explaining the Decline in UK Agricultural Productivity Growth." *Journal of Agricultural Economics* 55(2): 343-66.

2000-2008: DEFRA. Various editions and online. *Agriculture in the United Kingdom.* London: Her Majesty's Stationery Office.

Table 7.6 and Figures 7.3-7.6: Individual Output and Input Shares and Volume Indexes

1953-2000: Thirtle, C., L. Lin, J. Holding, and L. Jenkins. 2004. "Explaining the Decline in UK Agricultural Productivity Growth." *Journal of Agricultural Economics* 55(2): 343-66.

2000-2008: DEFRA. Various editions and online. *Agriculture in the United Kingdom.* London: Her Majesty's Stationery Office.

Figure 7.7: Sugar TFP

Thirtle, C. 1999. "Producer Funding of R&D: Productivity and the Returns to R&D in British Sugar, 1954-93." *Journal of Agricultural Economics* 50(3): 450-67.

Figure 7.8 and Table 7.7: Eastern Counties TFP and Its Decomposition

Amadi, J., J. Piesse, and C. Thirtle. "Crop Level Productivity in the Eastern Counties of England, 1970-95." *Journal of Agricultural Economics* 55(2): 343-36.

Figures 7.9-7.15 and Table 7.8: Productivity Comparisons for the EU and Acceding States

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Piesse, A. Kasterine, and G. Brooks. 2004. *Impact on UK Agriculture of Increasing Agricultural Productivity in EU Acceding Countries.* London: Final Report to DEFRA.

Table 7.9 and Figures 7.16-7.18: Explaining TFP—R&D, TFP, Patents, and Farm Size

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