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Comparisons of Capital Input in OECD Agriculture, 1973-2011

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Abstract: This paper provides a farm sector comparison of relative levels of capital input for 17 OECD countries for the period 1973-2011, with an explicit distinction between land and depreciable assets. Methodologically, we adopt the constant efficiency model to derive capital services from capital stocks and construct the purchasing power parity between countries for cross-country comparison. Our estimates show that, after accounting for cyclical fluctuation in the relative price of capital inputs, fifteen of the sixteen countries in the comparison had higher levels of capital input relative to the United States in 2011 than at the beginning of the sample period in 1973. Moreover, our analysis shows that increases in relative capital use on farms in OECD countries were accompanied by change in the structure of the capital input, away from land and towards depreciable capital items.

Keywords: Real capital input, Purchasing power parity, Perpetual inventory method, OECD agriculture

JEL Classifications: D24, N50, O47

1. Introduction

Productivity gains in agriculture over the past half century have enabled growth in global output to outpace population growth with only modest increases in total factor input. However, the rates of growth of productivity have been very uneven across countries, resulting in large differences in relative levels of productivity (see Ball, et al., 2001, 2010; Fuglie, et al. 2012; Gollin, et al. 2014a, 2014b; Herrendorf and Schoellman, 2015).

A number of recent studies point to differences in relative capital intensities as the proximate cause for this uneven performance (see Ball, et al. 2004; Ball, et al., 2008).This could be termed the embodiment hypothesis since it implies that technological innovation is embodied in capital. Our objective in this paper is to provide a comparison of relative levels of capital input in agriculture for 17 OECD countries for the period 1973-2011, with a distinction between land and depreciable assets.[1] In a subsequent paper, we integrate estimates of capital input into the production accounts for agriculture, including estimates of real output and real factor input. The accounts underpin efforts to measure relative levels of productivity in agriculture, with a focus on capital accumulation as a source of (conditional) convergence.

Construction of a measure of capital input begins with estimating the capital stock for each asset type. Estimates of depreciable capital input are derived by representing capital stock at each point in time as a weighted sum of past investments.[2] The weights correspond to the relative efficiencies of capital goods of different ages, so that the weighted components of capital stock have the same efficiency.

A problem associated with this approach is the implicit assumption of fixed asset lives. There is, in fact, wide variation in the service lives of capital assets, even among assets of the same type. Little information is available, however, on the actual service lives of assets. Thus, we adopt a set of assumptions that allow us to model variations in service lives and, once these service lives are determined, the rate of capacity depreciation or decline in efficiency of the capital stock.

To estimate the stock of land in each country, we first construct price indexes of land in agriculture. Observations on land in each country are differentiated by region and by land type. The stock of land is then constructed implicitly as the ratio of the value of land in agriculture to the corresponding price index.

Next, we convert estimates of capital stock into estimates of capital service flows. This is accomplished by means of capital rental prices. Implicit rental prices for each asset type are based on the correspondence between the purchase price of the asset and the discounted value of future service flows derived from that asset.

Comparisons of relative levels of capital input across countries require data on relative prices of capital input. We obtain relative prices for capital input via relative investment goods prices, taking into account the flow of capital services per unit of capital stock in each country.

Spatial differences in land characteristics or quality prevent the direct comparison of observed prices. Therefore, we need to construct indexes of relative prices for land in each country by using the hedonic method. This treatment provides a means of incorporating important but difficult to measure factors (related to agricultural production) such as environmental and natural resource endowments into productivity measures.

2. Model

In this section, we construct estimates of the capital stock and rental price for each asset type in each country. For depreciable assets, the perpetual inventory method is used to develop capital

[1] The countries are Belgium, Denmark, Germany, Greece, Spain, France, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Finland, Sweden, the United Kingdom, Australia, Canada and United States.

[2] Depreciable assets include transportation equipment, other machinery, and non-residential structures.

stocks from data on investment in constant prices.[3] For land, capital stocks are measured as implicit quantities derived from balance sheet data. Capital rental prices for each asset are based on the correspondence between the purchase price of the asset and the discounted value of future service flows derived from that asset.

2.1 Depreciable Assets

Under the perpetual inventory method, the capital stock at the end of each period, say K_t, is measured as the sum of all past investments, each weighted by its relative efficiency, say d_τ:

$$K_t = \sum_{\tau=0}^{\infty} d_\tau I_{t-\tau} \tag{1}$$

In equation (1), we normalize initial efficiency d_0 at unity and assume that relative efficiency decreases so that:

$$d_0 = 1,\ d_\tau - d_{\tau-1} \leq 0, \tau = 0,1,\ldots,T \tag{2}$$

We also assume that every capital good is eventually retired or scrapped so that relative efficiency declines to zero:

$$\lim_{\tau\to\infty} d_\tau = 0 \tag{3}$$

The decline in efficiency of capital goods gives rise to needs for replacement investment in order to maintain the productive capacity of the capital stock. The proportion of a given investment to be replaced at age τ, say m_τ, is equal to the decline in efficiency from age τ-1 to age τ:

$$m_\tau = -(d_\tau - d_{\tau-1}), \tau = 1,\ldots,T \tag{4}$$

These proportions represent mortality rates for capital goods of different ages.

Replacement requirements, say R_t, are a weighted sum of past investments:

$$R_t = \sum_{\tau=1}^{\infty} m_\tau I_{t-\tau}\ , \tag{5}$$

where the weights are the mortality rates.

Taking the first difference of expression (1) and substituting (4) and (5), we can write

$$K_t - K_{t-1} = I_t - \sum_{\tau=1}^{\infty}(d_\tau - d_{\tau-1})I_{t-\tau} = I_t - \sum_{\tau=1}^{\infty} m_\tau I_{t-\tau} = I_t - R_t \tag{6}$$

The change in capital stock in any period is equal to the acquisition of investment goods less replacement requirements.

To estimate replacement, we must introduce an explicit description of the decline in efficiency. This function, d, may be expressed in terms of two parameters, the service life of the asset, say L, and a curvature or decay parameter, say β. Initially, we will hold the value of L constant and evaluate the efficiency function for various values of β.

One possible form for the efficiency function is given by:

$$\begin{aligned} d_\tau &= (L - \tau)/(L - \beta\tau), 0 \leq \tau \leq L \\ d_\tau &= 0, \tau \geq L. \end{aligned} \tag{7}$$

This function is a form of a rectangular hyperbola that provides a general model incorporating several types of depreciation as special cases.

[3] Data on investment for member states of the European Union are from Beutel (1997). More recently, these data are from the Economic Accounts for Agriculture (Eurostat). For Australia, data are from the Australian Bureau of Statistics. Statistics Canada provided data for Canada, while data for the United States were provided by the US Department of Agriculture's Economic Research Service.

The value of β in (7) is restricted only to values less than or equal to one. Values greater than one yield results outside the bounds established by the restrictions on d. For values of β greater than zero, the function d approaches zero at an increasing rate. For values of β less than zero, d approaches zero at a decreasing rate.

Little empirical evidence is available to suggest a precise value for β. However, two studies provide evidence that efficiency decay occurs more rapidly in the later years of service. Utilizing data on expenditures for repairs and maintenance of 745 farm tractors covering the period 1958-74, Penson, Hughes and Nelson (1977) found that the loss of efficiency was very small in the early years of service and increased rapidly as the end of the asset's service life approached. More recently, Romain, Penson and Lambert (1987) compare the explanatory power of alternative capacity depreciation patterns for farm tractors in a model of investment behavior. They found that the concave depreciation pattern better reflects actual investment decisions.

Taken together, these studies suggest that estimates of β should be restricted to the zero-one interval. Ultimately, the β values selected for this study are 0.75 for structures and 0.5 for machinery and equipment. It is assumed that the efficiency of a structure declines slowly over most of its service life until a point is reached where the cost of repairs exceeds the increased service flows derived from the repairs, at which point the structure is allowed to deteriorate rapidly. The decay parameter for machinery and equipment assumes that the decline in efficiency is more uniformly distributed over the asset's service life.

We now consider the efficiency function that holds β constant and allows L to vary. The concept of variable lives is related to the concept of investment used in this study where investment is composed of different types of capital goods. Each of the different types is a homogeneous group of assets in which the actual service life L is a random variable reflecting usage, maintenance and repair patterns, or simply chance variation. For each type of capital good there exists some mean service life $\overline{L}$ around which there is a distribution of the actual service lives of the assets in the group. In order to determine the stock of capital available for production, the actual service lives and the relative frequency of assets with these service lives must be determined. We assume that this distribution may be accurately depicted by the standard normal distribution.

One property of the normal distribution is related to the infinite nature of the distribution. Without adjustment, the distribution would yield cases where assets were discarded prior to their purchase or assets with unrealistically long service lives. In order to eliminate these extremes, some adjustment is warranted. This adjustment involves truncation of the normal at some point before and after $\overline{L}$. The values of the normal are then adjusted upward within the allowed range of service lives.

In this study, we truncate the distribution at points two standard deviations before and after the mean. Two standard deviations are assumed to be 0.98 times the mean service life. This dispersion parameter was chosen to conform to the observation that assets are occasionally found that are considerably older than the mean service life and that a few assets are accidentally damaged when new. Once the frequency of a service life L is known, the decay function for that particular service life is calculated using the assumed value of β. A similar process is followed for all other possible values of L, and the decay functions are aggregated to derive a replacement function for that type of capital good. This function not only reflects changes in efficiency but also the discard distribution around the mean service life of the asset.

2.2 Land

To obtain the stock of land in each country, we first construct price indexes of land in agriculture. Observations on land in each country are differentiated by region and by land type in each country.[4] The stock of land is then constructed implicitly as the ratio of the value land in agriculture to the corresponding price index.

2.3 Capital Rental Prices

An important innovation in measuring capital input is the rental price of capital originated by Jorgenson (1963, 1973). However, this rental price is based on the particular assumption that the pattern of capacity depreciation is characterized by a decaying geometric series. The remaining task is to generalize the representation of the rental price to allow for any pattern of capacity depreciation.

To accomplish this task, we draw on the literature on investment demand (see Arrow, 1964; Coen, 1975; Penson, Hughes, and Nelson, 1977; Romain, Penson, and Lambert, 1987).We assume that firms buy and sell assets so as to maximize the present value of the firm. Let w_K denote the price the firm must pay for a new unit of capital, *p* the price the firm receives for each unit of output, and *r* the real discount rate. An increase in the capital stock *K* by one unit will increase output in each period by $\partial y/\partial K$, the marginal product of capital. Gross revenue in each period will rise by $p(\partial y/\partial K)$, but net revenue will rise by only $p(\partial y/\partial K) - w(\partial R_t/\partial K)$, where $\partial R_t/\partial K$ is the increase in replacement in period *t* required to maintain the capital stock at the new level. Firms should add to their capital stock if the present value of the net revenue generated by an additional unit of capital exceeds the purchase price of the asset. This can be stated algebraically as:

$$\sum_{t=1}^{\infty}\left(p\,\frac{\partial y}{\partial K} - w_K\,\frac{\partial R_t}{\partial K}\right)(1+r)^{-t} > w_K \qquad (8)$$

To maximize net present value, firms will continue to add to capital stock until this equation holds as an equality. This requires that:[5]

$$p\,\frac{\partial y}{\partial K} = r\,w_K + r\sum_{t=1}^{\infty} w_K\,\frac{\partial R_t}{\partial K}\,(1+r)^{-t} = c \qquad (9)$$

The expression for *c* is the implicit rental price of capital corresponding to the mortality distribution *m*. The rental price consists of two components. The first term, rw_K, represents the opportunity cost associated with the initial investment. The 2nd term, $r\sum_{t=1}^{\infty} w_K\,\frac{\partial R_t}{\partial K}\,(1+r)^{-t}$, is the present value of the cost of all future replacements required to maintain the productive capacity of the capital stock, multiplied by the discount rate.

Expression (9) can be simplified as follows. Let *F* denote the present value of the stream of capacity depreciation on one unit of capital according to the mortality distribution *m*; that is:

$$F = \sum_{\tau=1}^{\infty} m_\tau\,(1+r)^{-\tau} \qquad (10)$$

It can be shown that:

$$\sum_{t=1}^{\infty} \frac{\partial R_t}{\partial K}\,(1+r)^{-t} = \sum_{t=1}^{\infty} F^t = \frac{F}{(1-F)} \qquad (11)$$

[4] We compile data on land area and average value per hectare for 3,582 States or regions across the seventeen countries.

[5] If $r > 0$, then $\sum_{t=1}^{\infty}(1+r)^{-t} = \frac{1}{r}$. Substituting this result in (8) and rearranging terms yields expression (9).

so that $$c = \frac{r\, w_K}{(1 - F)}$$ [6] (12)

The real rate of return *r* in equation (12) is calculated as the nominal yield on government bonds, less the rate of inflation as measured by the implicit deflator for gross domestic product. An *ex ante* rate is obtained by expressing inflation as an ARIMA process.[7] Implicit rental prices *c* are then calculated for each asset type in each country using the expected real rate of return.

3. Real Capital Input

In the previous section, we outlined the development of data on capital stocks and rental prices of capital services. To conserve space we do not report asset-specific estimates of capital stock and capital rental prices[8]. Rather, we report in Table 1 Tőrnqvist price indexes of capital input in each country formed by aggregating over the various asset types (i.e. transportation equipment, other machinery, non-residential structures, and land). In Table 2 we report the quantities of capital input in each country, formed implicitly by taking the ratio of the value of capital services to the price index of capital input. These data are the basis for our estimates of real capital input across countries.

Comparisons of relative levels of capital input among countries also require data on the relative prices of capital input. A price index that converts the ratio of the nominal values of capital service flows between two countries into an index of real capital input is referred to as a purchasing power parity of the currencies of the two countries. The dimensions of the purchasing power parities are the same as exchange rates. However, the purchasing power parities reflect the relative prices of the components of capital input in each country.

Although we estimate the decline in efficiency of capital goods separately for all seventeen countries, we assume that the relative efficiency of new capital goods is the same in each country. Therefore, the appropriate purchasing power parity for new capital goods is the purchasing power parity for the corresponding component of investment goods output (World Bank, 2008). To obtain the purchasing power parities for capital input, we must take into account the flow of capital services per unit of capital stock in each country. This is accomplished by multiplying the purchasing power parities for capital goods for any two countries by the ratio of the prices of capital input for the two countries. The resulting price index represents the purchasing power parity for capital input.

[6] For the special case where $d_\tau = \delta(1-\delta)^{\tau-1}$, which was assumed by Jorgenson (1963, 1973),

$$F = \sum_{\tau=1}^{\infty} \delta(1-\delta)^{\tau-1}(1+r)^{-\tau} = \delta/(r+\delta) \quad \text{and} \quad c = w_K(r+\delta),$$

which is the expression for the rental price commonly found in the literature.

[7] Price inflation is expressed as an AR(1) process. We use this specification after examining the correlation coefficients for autocorrelation, partial and inverse autocorrelation, and performing the unit root and while noise tests.

[8] Estimates of capital stock by asset types in each of the seventeen OECD countries, the corresponding rental prices and the capital inputs are available upon request from the authors.

Year	Belgium	Denmark	Germany	Greece	Spain	France	Ireland	Italy	Luxem-burg	NL	Portugal	Finland	Sweden	UK	Australia	Canada	US
1973	0.2563	0.0772	0.3184	0.0321	0.1995	0.1895	0.2117	0.1474	0.2673	0.1987	0.0253	0.1190	0.1544	0.2729	0.1141	0.3587	0.3982
1974	0.3114	0.1591	0.3661	0.0493	0.2589	0.2312	0.3896	0.2005	0.2556	0.2433	0.0312	0.1542	0.1635	0.3227	0.1270	0.3903	0.3957
1975	0.3499	0.1375	0.3409	0.0530	0.2032	0.2803	0.5371	0.1975	0.2749	0.2504	0.0297	0.1640	0.1900	0.3489	0.1366	0.4008	0.3180
1976	0.3605	0.1295	0.2893	0.0563	0.2140	0.2913	0.6539	0.2051	0.3075	0.2545	0.0285	0.2106	0.1997	0.3549	0.1500	0.4327	0.3198
1977	0.3485	0.1466	0.2565	0.0604	0.2185	0.2886	0.6115	0.2107	0.3819	0.2647	0.0375	0.2667	0.2079	0.2486	0.1641	0.3962	0.6382
1978	0.3213	0.2125	0.2406	0.0681	0.2857	0.2897	0.4619	0.1824	0.3722	0.2783	0.0554	0.3388	0.2187	0.1768	0.1790	0.4877	0.6261
1979	0.3732	0.3018	0.3268	0.0860	0.2773	0.2877	0.4259	0.1820	0.3928	0.2935	0.0599	0.4175	0.2337	0.2006	0.1944	0.6160	0.8068
1980	0.6067	0.3696	0.5109	0.1370	0.3570	0.3124	0.3418	0.2938	0.4256	0.3521	0.0748	0.5505	0.2772	0.2251	0.2129	0.9090	1.0504
1981	0.9031	0.4410	0.7818	0.2105	0.2981	0.4283	0.4344	0.3667	0.4755	0.4453	0.0962	0.6730	0.3637	0.2424	0.2728	1.3688	1.5687
1982	1.0881	0.5890	0.8837	0.2600	0.3822	0.5877	0.4698	0.4291	0.5952	0.5085	0.1561	0.7147	0.3952	0.2581	0.3671	1.2752	1.4567
1983	1.0419	0.4817	0.8759	0.2721	0.5628	0.6741	0.4323	0.4489	0.6090	0.5290	0.2698	0.7135	0.4308	0.2680	0.3516	1.0144	1.5944
1984	1.0767	0.4653	0.8707	0.2769	0.6282	0.6756	0.4792	0.4551	0.6497	0.5120	0.3690	0.7993	0.4698	0.3733	0.3633	1.3641	1.7026
1985	1.0899	0.4003	0.9137	0.2681	0.6031	0.6566	0.4934	0.4564	0.6925	0.5562	0.3246	0.8666	0.4945	0.5047	0.4911	1.3634	1.4510
1986	0.9969	0.4757	0.8972	0.3137	0.6558	0.6493	0.4460	0.4892	0.7027	0.6592	0.4253	0.8545	0.4790	0.4577	0.6228	1.2560	1.0227
1987	0.9633	0.7052	0.8675	0.3998	0.7416	0.7317	0.4326	0.5477	0.7860	0.7423	0.5434	0.9205	0.4875	0.5706	0.7376	1.3834	1.1822
1988	1.0110	0.7049	0.9190	0.4942	0.9933	0.8488	0.5143	0.5875	0.8395	0.8779	0.5443	1.0159	0.5187	0.5754	0.8110	1.3363	1.1610
1989	1.1530	0.7910	1.0050	0.6231	1.3771	0.9753	0.6491	0.8624	0.9952	0.9877	0.6665	1.1232	0.5931	0.6207	0.8863	1.4546	1.1666
1990	1.2094	0.8054	1.1537	0.7496	1.7868	1.1665	0.7706	1.0101	1.3415	1.1300	0.6619	1.2446	0.7014	0.7290	0.8920	1.6756	1.1947
1991	1.2775	0.7112	1.3041	1.0283	1.6746	1.2827	0.8032	1.0517	1.4462	1.2548	0.6333	1.2754	0.7026	0.4880	0.8493	1.6276	1.0525
1992	1.3103	0.8060	1.3319	1.1604	1.5862	1.3287	1.0059	1.2479	1.6509	1.2542	0.5451	1.1040	0.6592	0.5146	0.8669	1.5603	0.9008
1993	1.1846	0.7973	1.1560	1.3555	1.2819	1.2318	1.0856	1.3667	1.4800	1.1481	0.4882	0.9657	0.5968	0.5310	0.8562	1.6271	0.9107
1994	1.0931	0.9139	1.0591	1.4579	1.2575	1.2073	0.9887	1.4397	1.3663	1.0968	0.6941	0.9754	0.6991	0.7041	0.9914	1.7600	1.2606
1995	1.1431	0.9641	1.0750	1.4259	1.7723	1.2591	1.1944	1.6851	1.4460	1.1338	0.9921	1.0289	0.9095	1.0663	1.1358	1.8964	1.3040
1996	1.1104	1.0319	1.0979	1.3689	1.7164	1.2264	1.2445	1.7374	1.4742	1.0994	1.2336	0.7023	0.9413	1.2410	1.0912	1.6660	1.3302
1997	1.1541	0.9706	1.1173	1.0843	1.2337	1.1918	1.2602	1.5284	1.3574	1.0768	1.3345	0.8375	0.9098	1.1031	1.0080	1.7289	1.5826
1998	1.1472	0.9121	1.0899	1.0207	0.8920	1.1056	1.1717	0.9587	1.2697	0.8934	1.0819	0.7677	0.8318	0.9956	0.9336	1.9080	1.3845
1999	1.2231	0.9254	1.0626	1.0555	0.7490	1.0973	1.0834	0.9340	1.4136	0.9580	0.8192	0.6728	0.8163	0.9397	0.9805	2.4038	1.6914
2000	1.2619	1.0137	1.1376	0.9964	0.8927	1.1642	1.0669	1.1761	1.6670	1.1693	0.8891	0.8789	0.8952	0.9792	1.0494	2.1572	1.8229
2001	1.2361	0.9985	1.2299	0.8514	1.2241	1.2183	1.0430	1.2308	1.6912	1.0801	0.9982	0.8686	0.9040	1.1302	0.9080	1.5349	1.2260
2002	1.1869	0.9984	1.1938	0.9691	1.1550	1.2429	0.9667	1.0906	1.8026	0.9698	1.0173	0.8286	0.9820	1.2246	0.8611	2.0705	1.0818
2003	1.1101	0.9493	1.0690	0.9233	1.1096	1.1891	0.9726	0.8970	1.5327	0.8566	0.9393	0.8699	1.0673	0.9787	0.9027	2.0630	1.0277
2004	1.0912	1.0260	0.9950	0.9191	0.9315	1.0984	0.9723	0.8944	1.2070	0.8938	0.9904	1.0515	0.9911	0.9836	0.9776	1.3889	0.9033
2005	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2006	0.9924	0.9668	1.0232	0.9798	1.0627	0.9754	0.9722	1.1374	1.1470	0.9849	1.0641	1.0562	0.9991	0.9777	0.9554	1.3513	1.3582
2007	1.0607	1.1370	1.1089	1.1216	1.1366	1.0278	0.9309	1.3491	1.4686	1.1169	1.1190	1.1566	1.0686	1.1479	0.9657	1.6109	1.4102
2008	1.1498	1.2729	1.1923	1.2455	1.4044	1.0806	1.2968	1.3985	1.6650	1.3254	1.5838	1.0859	1.0175	1.3226	0.9935	1.1635	1.1146
2009	1.1907	1.0346	1.1518	1.0929	1.4109	1.1153	1.8314	1.3563	1.7766	1.2898	2.1912	1.0074	0.9622	0.8869	0.9005	1.3377	1.0020
2010	1.2408	1.1352	1.0840	1.6742	1.8621	1.0709	2.6459	1.4334	1.5712	1.3585	3.1663	0.9831	0.9336	1.0919	1.2024	2.1394	1.0522
2011	1.3431	0.8113	1.0519	2.5048	1.5963	1.0845	3.6813	2.2654	1.3265	1.4393	5.3605	1.1046	0.9437	0.7453	1.0189	1.3216	1.0352

Table 1. Price Indexes of Capital Input, 1973-2011

Estimating purchasing power parities for land input proves more difficult. Spatial differences in land characteristics or quality prevent the direct comparison of observed prices. Land in agricultural production is heterogeneous in terms of soil type and associated soil characteristics.

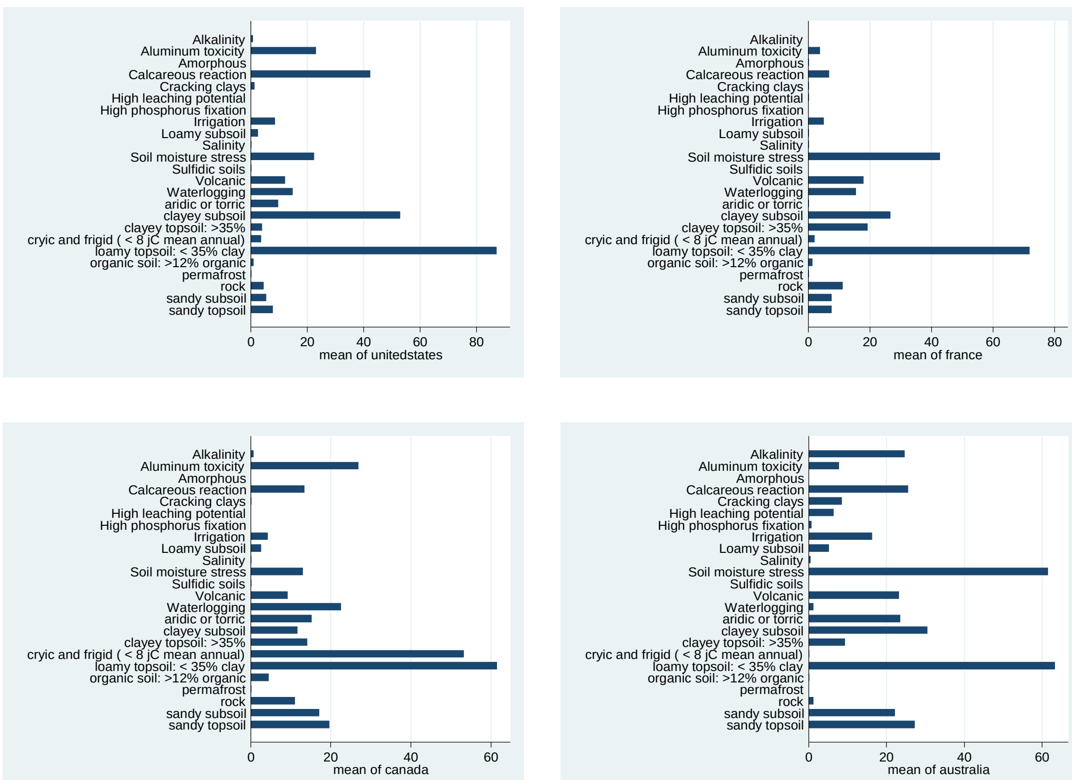
Failure to account for these differences would lead to biased estimates of relative land input. Therefore, we construct indexes of relative prices of land using hedonic methods.

Table 2. Capital Input (Millions of 2005 national currencies)

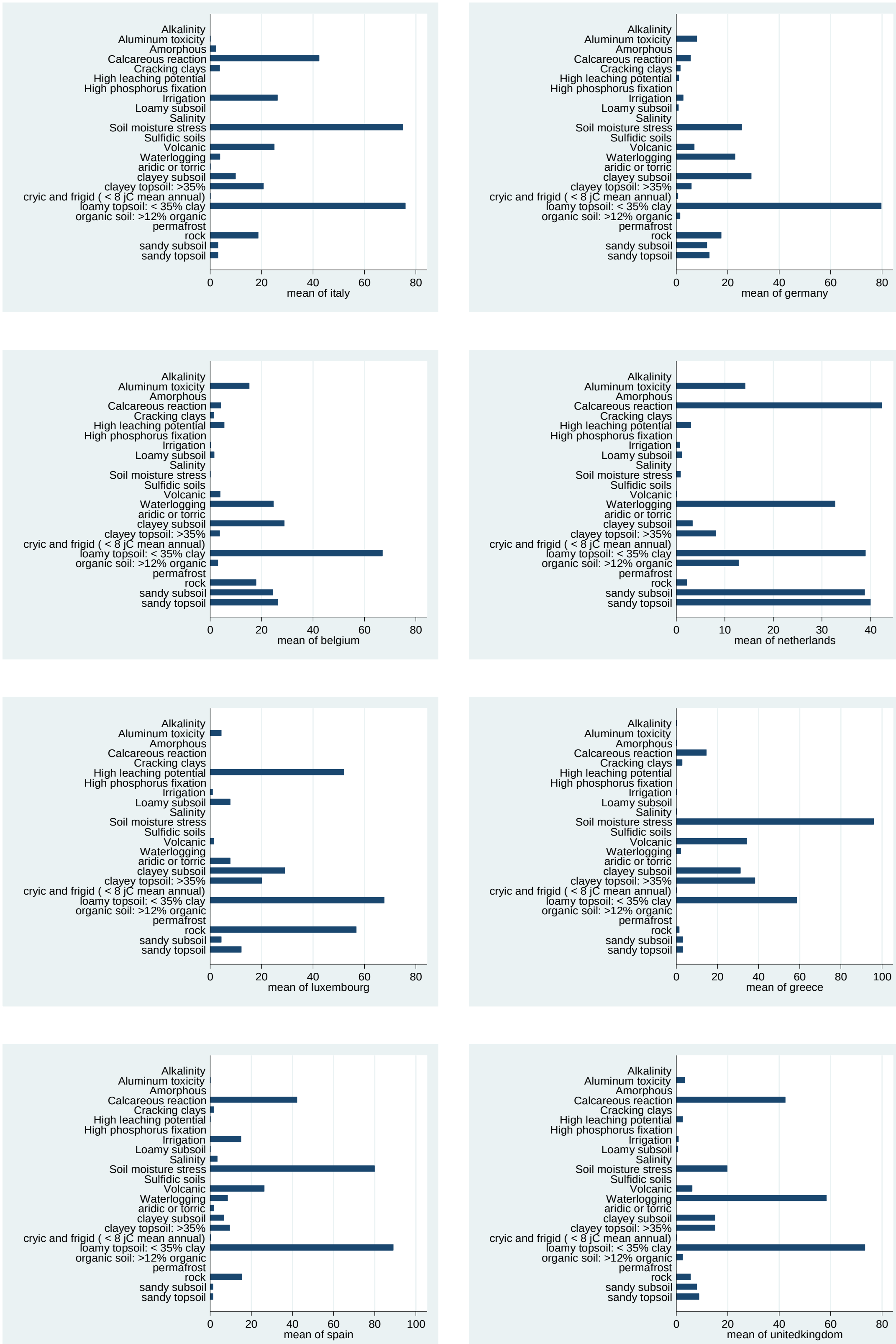
Year	Belgium	Denmark	Germany	Greece	Spain	France	Ireland	Italy	Luxem-burg	NL	Portugal	Finland	Sweden	UK	Australia	Canada	US
1973	934	16456	16905	1795	3407	9682	1026	8852	81	2153	738	1789	12513	4262	10298	3591	33147
1974	977	17312	17063	1827	3446	10055	1056	8949	83	2314	787	1796	12365	4321	10620	3799	34002
1975	1017	18199	17097	1861	3440	10411	1041	8967	84	2464	847	1811	12322	4403	10904	4048	35055
1976	1023	19164	17161	1929	3461	10681	1046	9061	85	2553	914	1832	12464	4407	11211	4374	35782
1977	1037	20252	17302	1989	3492	10957	1068	9228	85	2659	963	1852	12659	4360	11596	4782	35424
1978	1062	21001	17584	2045	3534	11166	1091	9432	83	2855	1018	1865	12663	4468	11932	5057	35942
1979	1099	21755	17486	2061	3603	11444	1124	9690	84	3093	1054	1872	12552	4514	12299	5309	36580
1980	1108	22402	17600	2131	3676	11709	1160	9697	84	3306	1095	1886	12445	4540	12777	5559	37144
1981	1102	22521	17625	2191	3845	11893	1186	9805	84	3411	1132	1913	12165	4499	12851	5668	37027
1982	1093	22382	17539	2213	3919	12031	1221	9839	83	3485	1159	1937	11927	4480	13112	5698	36651
1983	1089	22199	17453	2237	3966	12179	1236	9857	84	3560	1158	1974	11764	4509	13320	5642	35894
1984	1079	22161	17444	2236	4008	12257	1237	9853	85	3673	1157	1967	11627	4498	13539	5521	35148
1985	1073	22173	17380	2230	4046	12317	1234	9851	84	3721	1145	2025	11573	4565	13764	5413	34360
1986	1064	22384	17317	2244	4048	12329	1226	9848	83	3764	1128	2038	11379	4595	13895	5217	33169
1987	1061	22535	17228	2160	4069	12271	1218	9844	81	3773	1124	2028	11111	4570	13933	5005	31857
1988	1058	22521	17133	2055	4077	12219	1204	9847	80	3800	1139	2038	10884	4545	13968	4798	30955
1989	1053	22372	17081	1973	4052	12199	1198	9882	80	3820	1203	2046	10746	4507	14080	4596	30170
1990	1047	22449	18235	1914	4009	12261	1206	9905	79	3857	1249	2021	10685	4489	14200	4421	29579
1991	1043	22430	18098	1845	3932	12290	1213	9892	80	3891	1233	2065	10539	4483	14222	4245	29110
1992	1031	22281	18095	1784	3887	12281	1212	9861	81	3923	1214	2049	10250	4424	14171	4098	28492
1993	1035	21686	18137	1735	3793	12211	1207	9807	81	3959	1200	1978	9923	4384	14134	3968	27798
1994	1025	20984	18042	1668	3696	12107	1202	9715	80	3930	1164	1921	9595	4393	14058	3918	27254
1995	1008	21013	17888	1612	3610	12046	1210	9654	80	3895	1140	1881	9412	4411	14024	3867	26863
1996	995	21113	17732	1572	3556	12043	1214	9591	79	3877	1116	1834	9256	4445	14098	3837	26467
1997	987	21300	17607	1544	3557	12092	1234	9549	78	3844	1102	1820	9118	4460	14180	3801	26224
1998	982	21438	17508	1528	3550	12173	1234	9534	77	3843	1093	1823	9020	4441	14307	3838	26088
1999	979	21224	17296	1528	3559	12293	1239	9521	77	3839	1082	1824	8909	4377	14530	3889	26014
2000	978	21209	17210	1549	3530	12423	1239	9512	75	3859	1085	1835	8866	4276	14714	3878	25845
2001	976	21377	17161	1592	3523	12507	1236	9535	74	3868	1087	1839	8979	4247	14850	3870	25710
2002	978	21567	17052	1592	3521	12566	1230	9543	73	3908	1089	1845	9069	4215	14963	3835	25718
2003	983	21593	17044	1625	3534	12600	1226	9640	72	3899	1089	1859	9210	4174	15112	3827	25759
2004	986	21720	16946	1676	3564	12650	1219	9723	73	3908	1088	1878	9300	4154	15343	3819	26048
2005	989	22001	16852	1708	3616	12729	1219	9863	75	3903	1091	1874	9390	4157	15528	3855	26590
2006	995	22160	16633	1766	3608	12786	1216	9928	75	3889	1087	1897	9410	4179	15759	3803	26714
2007	1009	22187	16543	1800	3630	12849	1223	9975	76	3900	1082	1893	9456	4161	16015	3757	26552
2008	1039	22621	16509	1870	3676	12984	1268	9977	75	3971	1080	1882	9597	4190	16177	3813	26695
2009	1043	22672	16610	1944	3719	13166	1296	10089	76	4040	1078	1881	9793	4201	16500	3855	27290
2010	1071	22580	16457	1951	3761	13195	1280	10046	77	4035	1074	1909	9864	4238	16892	3887	27217
2011	1093	22442	16366	1960	3775	13111	1267	9989	78	4047	1071	1885	9908	4284	17305	3966	27286

A hedonic price function expresses the price of a good or service as a function of the quantities of the characteristics it embodies. Thus, the hedonic price function for land may be expressed as $w_L = W(X, D)$, where w_L represents the price of land, X is a vector of characteristics or quality variables, and D is a vector of variables to be defined.

Sanchez, et al. (2003) introduced a soil taxonomy that could be used to identify attributes relevant for crop production. A complete list of attributes, along with definitions, is provided in Sanchez, et al. (2003), while Figure 1 depicts their levels.[9] The attributes most common in major agricultural countries are loamy topsoil (particularly in the United States, Portugal and Spain) and moisture stress (particularly in Australia, Greece, Italy, Portugal, and Spain). In areas with moisture stress, agriculture is not possible without irrigation. Hence irrigation (*i.e.*, the percentage of the cropland that is irrigated) is included as a separate variable. We also include the interaction between moisture stress and irrigation in the hedonic regression.



[9] Sanchez, et al. (2003) provide a global assessment of land resources. Using the Sanchez, et al. database, we apply GIS techniques to overlay state and regional boundaries. This overlay gives us the proportion of the land area in each region that exhibits a particular attribute.


Alkalinity
Aluminum toxicity
Amorphous
Calcareous reaction
Cracking clays
High leaching potential
High phosphorus fixation
Irrigation
Loamy subsoil
Salinity
Soil moisture stress
Sulfidic soils
Volcanic
Waterlogging
aridic or torric
clayey subsoil
clayey topsoil: >35%
cryic and frigid (< 8 jC mean annual)
loamy topsoil: < 35% clay
organic soil: >12% organic
permafrost
rock
sandy subsoil
sandy topsoil
0 20 40 60 80
mean of italy
0 20 40 60 80
mean of germany
0 20 40 60 80
mean of belgium
0 10 20 30 40
mean of netherlands
0 20 40 60 80
mean of luxembourg
0 20 40 60 80 100
mean of greece
0 20 40 60 80 100
mean of spain
0 20 40 60 80
mean of unitedkingdom

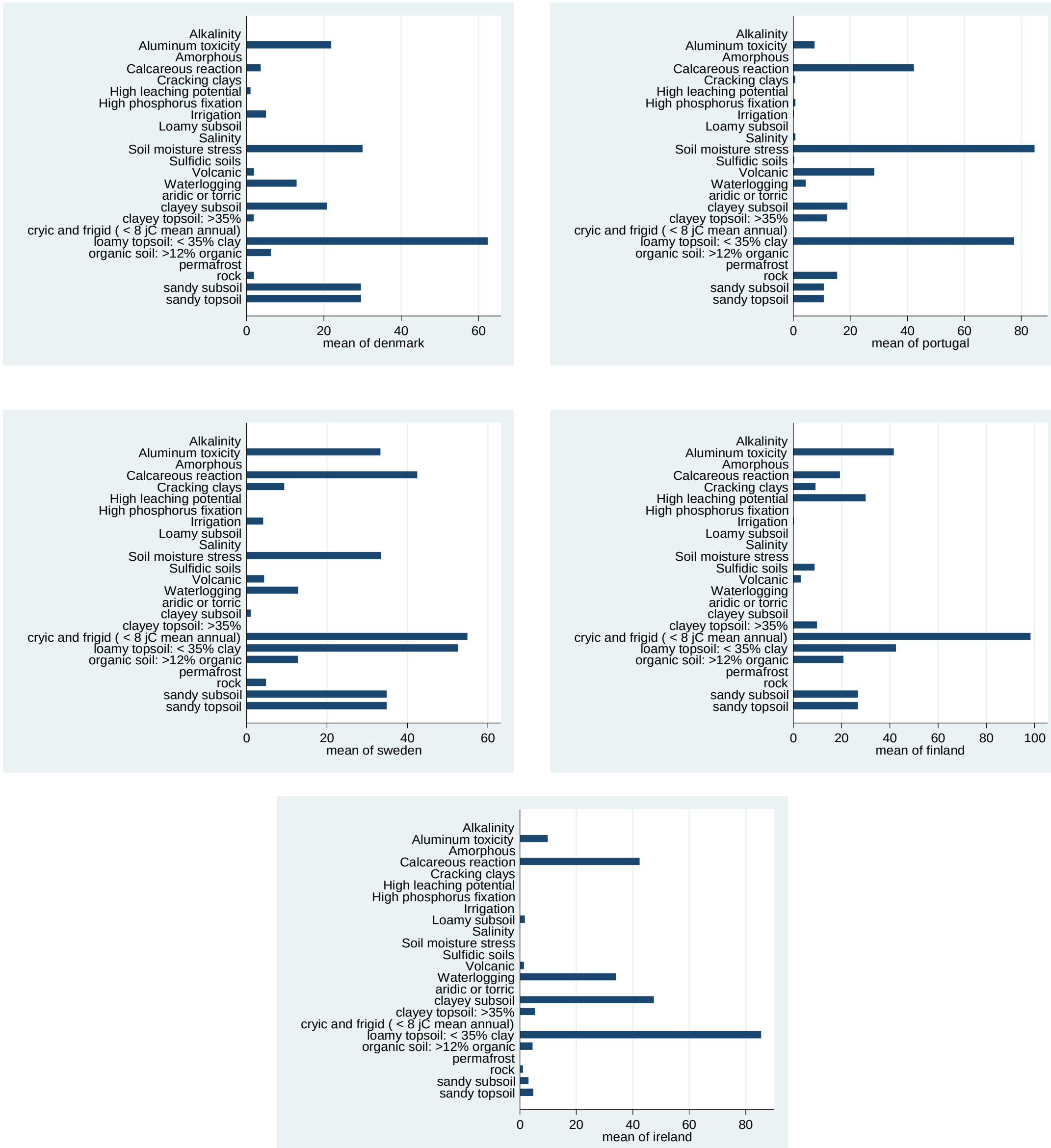


Figure 1. Levels of land attributes for 17 OECD countries

In addition to environmental attributes, we include a "population accessibility" score for each region in each country. This index is constructed using a gravity model of urban development, which provides a measure of accessibility to population concentrations (Shi, et al., 1997). A gravity index accounts for both population density and the distance from that population. The index increases as population increases and/or distance from the population center decreases.

Other variables (denoted by *D*) are included in the hedonic regression, and their selection depends not only on the underlying theory but also on the objectives of the study. If the main objective of the study is to obtain price indexes adjusted for quality, as in our case, the only variables that should be included in *D* are country dummy variables, which will capture all price effects other than quality. After allowing for differences in the levels of the attributes, the part of the price difference not accounted for by the included attributes will be reflected in the country dummy coefficients.

Finally, economic theory places few if any restrictions on the functional form of the hedonic price function. In this study, we adopt a generalized linear form, where the dependent variable and each of the continuous independent variables is represented by the Box-Cox transformation. As a practical matter we estimate the LHS as the log of land and apply the Box-Cox transformation to the RHS. This is a mathematical expression that assumes a different functional form depending on the transformation parameter, and which can assume both linear and logarithmic forms, as well as intermediate non-linear functional forms.

Thus the general functional form of our model is given by:

$$w_L(\lambda_0) = \sum_{n=1}^{N} \alpha_n X_n(\lambda_n) + \sum_{m=1}^{M} \gamma_m D_m + \varepsilon \qquad (13)$$

where $w_L(\lambda_0)$ is the Box-Cox transformation of the dependent price variable, $w_L > 0$; that is:

$$w_L(\lambda_0) = \begin{cases} \dfrac{w_L^{\lambda_0} - 1}{\lambda_0}, \lambda_0 \neq 0, \\ \ln w_L, \lambda_0 = 0. \end{cases} \qquad (14)$$

Similarly, $X_n(\lambda_n)$ is the Box-Cox transformation of the continuous quality variable X_n where $X_n(\lambda_n) = (X_n^{\lambda_n} - 1)/\lambda_n$ if $\lambda_n \neq 0$ and $X_n(\lambda_n) = \ln X_n$ if $\lambda_n = 0$. Variables represented by *D* are country dummy variables, not subject to transformation; λ, α, and γ are unknown parameter vectors, and ε is a stochastic disturbance. The dependent variable, the price of land, as the logarithm of land, i.e. $\lambda = 0$. Hence, the exponentiation county dummies can be shown to represent the nominal value of the of the quality-adjusted land value by country (Ball, et al., 2010).

Ordinarily, estimating a Box-Cox model is straightforward. However, the fact that our model contains dichotomous variables with values equal to zero at some point(s) makes for a more difficult application of this procedure. Since the Box-Cox transformation involves logarithms, and the logarithm of zero is not defined, one cannot simply fit the Box-Cox model to the data. In response to this problem, we do not transform those quality variables with values of zero.

Several methods have been used to calculate price indexes adjusted for quality using hedonic functions, including characteristics prices and dummy variable techniques. The latter is used in this study because it is simpler and because Triplett (1989) has provided extensive evidence of the robustness of the hedonic price indexes to the method of calculation. Using the dummy variable approach, quality-adjusted price indexes are calculated directly from the coefficients on the country dummy variables *D* in the hedonic regression.[10]

Table 3 reports the estimation results for our hedonic price model. Continuous variables include clayey topsoil, loamy topsoil, sandy topsoil, moisture stress, irrigation, and population accessibility. However, because of the extraordinary heterogeneity of the soils across States and regions, a number of attributes are included as dummy variables. These include aluminum toxicity, salinity, aridic or torric soils, water-logging, high phosphorus fixation, alkalinity, cryic and frigid, permafrost, cracking clays, volcanic soils, high organic content, and rock. In each case, the variable takes on a value of one if the level of the attribute exceeds a threshold value, defined as the mean level over all observations, and zero otherwise. Referring to Table 3, the price of land is positively correlated with loamy topsoil, sandy topsoil, irrigation, and population accessibility, as expected.

[10] Using the parameter estimates from Table 2, the quality adjusted price index for land for country *i* relative to the United States is given by $e^{(D_i - D_{US})}$.

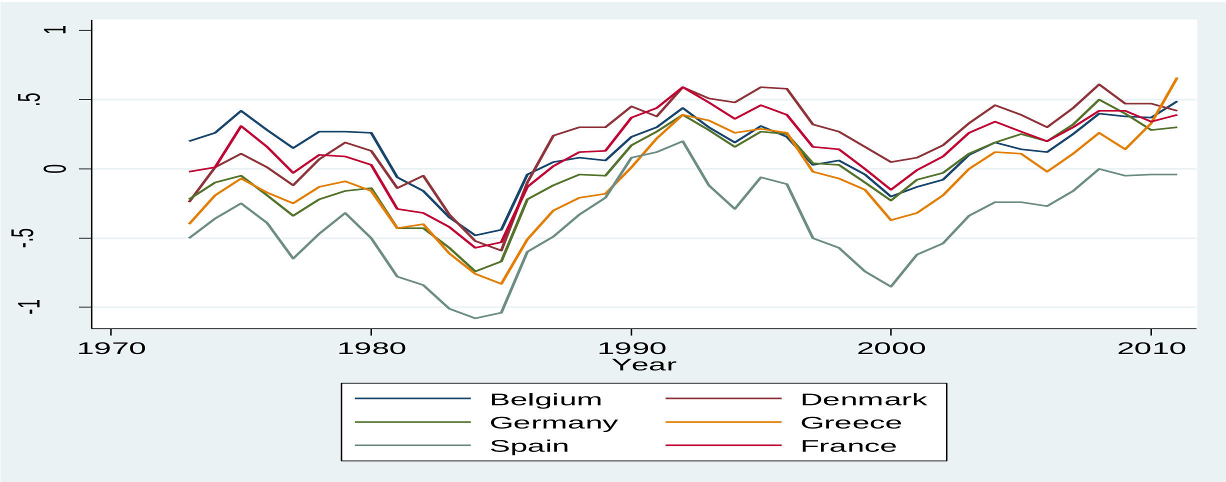
The coefficient on the interaction term between irrigation and moisture stress is also positive and significant. Moisture stress has a negative and significant impact on land prices, as do aridic or torric soils. But water-logging (poorly drained soils) is positively correlated with the price of land, which is not entirely intuitive.

Typical of poorly drained soils is a clayey subsoil that has sufficient anion exchange capacity to hold nitrogen against leaching. Another positive consequence of subsoil anion exchange capacity is the ability of the soil to hold some anions that can turn into pollutants if leached, including phosphates. When combined with management practices such tiling these soils are highly suitable for production of cereals.

We report in Table 4 the purchasing power parities for capital input defined over the four asset categories.[11] These are relative prices of capital input expressed in terms of national currencies per dollar. As a final step, we divide the relative prices of capital input by the exchange rate to translate purchasing power parities into relative prices in dollars. This allows us to decompose the values of capital service flows into price and quantity components. We report relative prices of capital input in Table 5, while Table 6 provides real values of capital input in each country.

3.1 Relative Prices of Capital Input

In Figure 2, we plot relative prices of capital input over the 1973-2011 period. We have expressed these prices in logarithmic form so that a positive difference implies that the price of capital input in the comparison country is above the United States price, while a negative difference implies a higher price in the United States.



[11] We have constructed indexes of relative prices for the seventeen countries for the base year 2005 (see Caves et al., 1982). We have also constructed price indexes of capital input in each country for the period 1973-2011. We obtain indexes of capital input prices in each country relative to the United States for each year by linking the time series price indexes with estimates of relative prices for the base year.

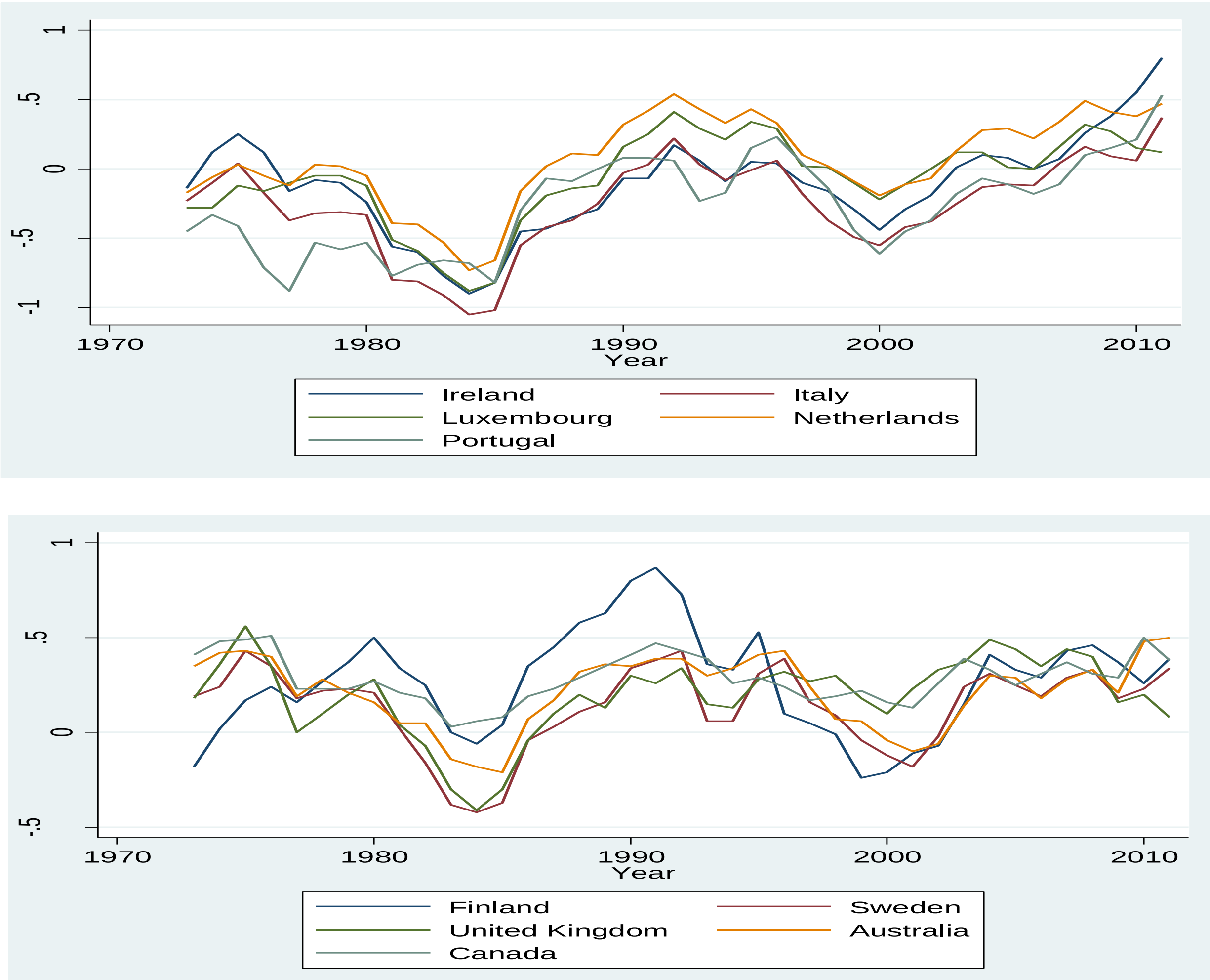


Figure 2. Trends of differences in relative capital input prices denominated in dollars

3.2 Relative Levels of Capital Input

Relative levels of capital input are shown in Figure 3. Fifteen of the sixteen countries in our sample had higher levels of capital input relative to the United States in 2011 than they had at the beginning of the study period in 1973. The largest increase in capital input was achieved by the Netherlands, with a doubling of capital input relative to the United States between 1973 and 2011, followed by Australia. Only Sweden saw the relative level of capital input decline over this period.

More telling are the patterns of growth over various subperiods. All seventeen countries increased absolute levels of capital input in agriculture between 1973 and 1979. One reason for this is that, as noted earlier, the 1970s were characterized by high rates of inflation. Monetary restraint was not sufficient to cause interest rates to rise as fast as the rate of inflation. As a result, real interest rates fell sharply. For a time in the middle 1970s, real rates were actually negative.

Contributing to the already high rates of inflation was the spike in energy prices following the 1973 oil embargo. The major oil exporting countries then recycled "petrodollars" through developing countries, fueling rapid growth in demand for agricultural exports (Desta 2003).

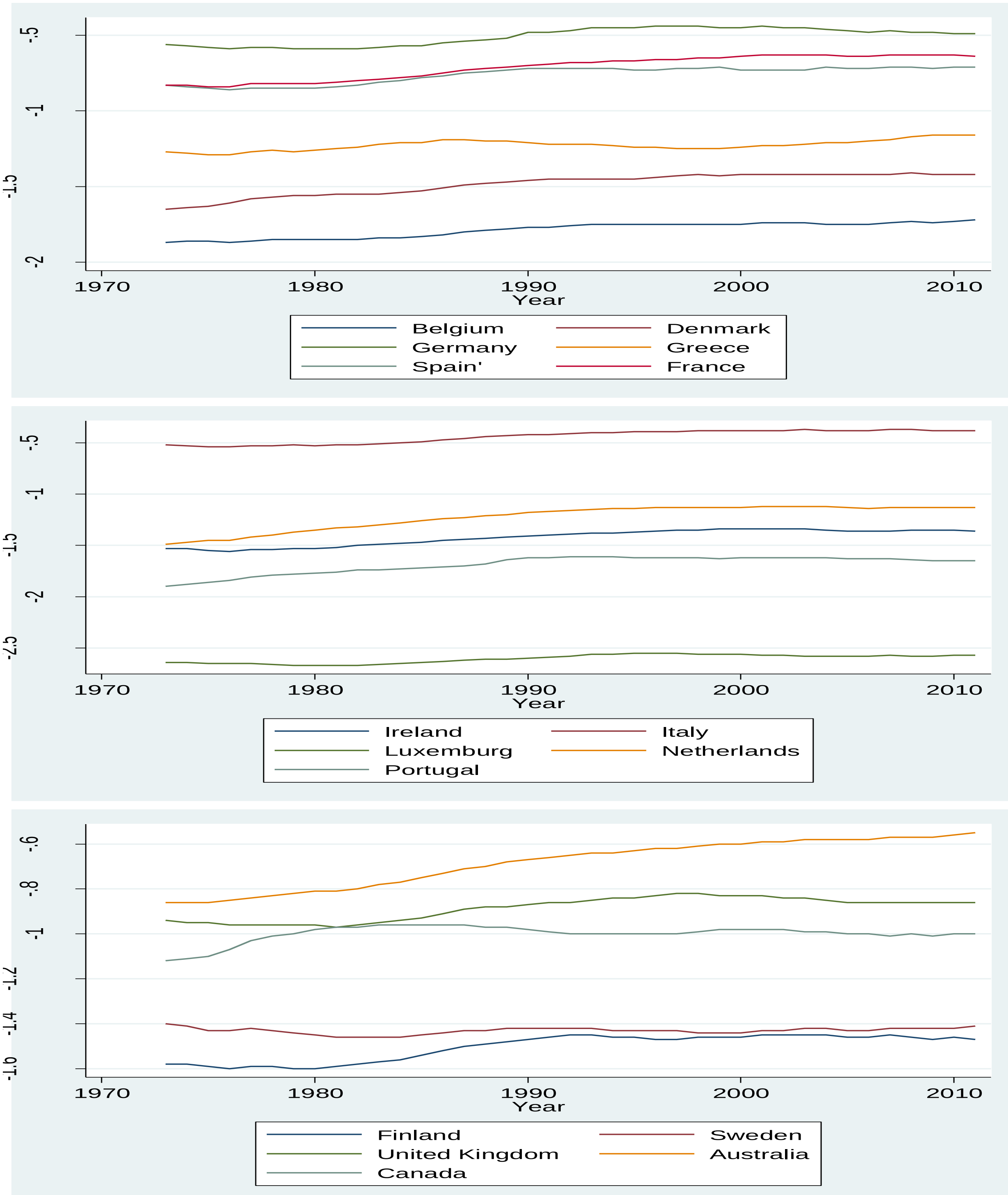


Figure 3. Trends of differences in relative capital input

Relative capital input prices trended higher during the 1970s. We attribute this to two developments, high rates of inflation in the United States and a weakening dollar, both of which are interrelated (Feldstein, 1978; 1980). The high rates of inflation actually originated in the monetary and fiscal policies of the late 1960s.

During the late 1960s, increases in government spending outpaced revenue growth, resulting in large deficits. Given the fiscal stimulus, the Federal Reserve could not hope to keep interest rates down and, simultaneously, restrain money growth.

Monetary policy was conducted so as to stabilize interest rates. But in order to stabilize interest rates when there was a large deficit, the central bank had to expand the money supply. The Federal Reserve provided sufficient money and credit to finance both the budget deficit and the demand for private credit without raising interest rates unduly. The result of monetary expansion, however, was high rates of inflation.

A related development was the falling value of the dollar on foreign exchange markets. In 1971, the United States, lacking sufficient gold reserves to defend the dollar's fixed exchange rate, abrogated the Bretton Woods agreement and began the transition to a floating exchange rate, which was realized in March 1973. This shift resulted in the depreciation of the dollar against other major currencies, with the dollar losing roughly a third of its value from 1970 to 1979. Relative prices of capital input reached a (temporary) peak in that year.

The situation changed in the early 1980s when the Federal Reserve Board changed course on monetary policy, targeting the money supply to allow interest rates to rise. As a result, the dollar appreciated some 60 percent on foreign exchange markets between 1979 and 1985. By 1985, prices of capital input, denominated in dollars, had fallen to their lowest levels relative to the United States.

Relative prices increased after 1985, a consequence of a weakening dollar and declining capital costs in the United States, reaching a peak in the early 1990s. But the subsequent strength of the dollar resulted in a decline in relative prices. By 2001, prices of capital input were again below the United States level. A weaker dollar after 2001 produced yet another break in trend, as relative prices moved higher. The financial crisis of 2008 and the accompanying spike in interest rates pushed relative prices of capital input in Ireland and Portugal to record levels.

Table 3. Regression of Land Prices on Characteristics

Variable	Coefficient	t-value	Variable	Coefficient	t-value
D1 (US)	8.780178***	68.33	Irrigation	0.044185***	3.47
D2 (Canada)	8.715092***	62.91	Moisture stress	-1.407117**	-2.89
D3 (Australia)	8.147432***	25.70	Irrigation*moisture stress	0.0492249***	4.37
D4 (France)	8.266801***	39.39	Population accessibility	0.3777769***	30.71
D5 (Finland)	8.537561***	8.48	Aluminum toxicity	0.010853	0.84
D6 (UK)	8.048193***	10.26	Salinity	0.000971	0.18
D7 (Ireland)	9.577729***	3.92	Aridic torric	-0.070154***	-9.47
D8 (Belgium)	8.818908***	4.52	Waterlogging	0.074809***	3.32
D9 (Denmark)	10.986746***	9.16	High phosphorus	0.021248	0.14
D10 (Lux.)	9.019151	0.36	Alkalinity	0.026959	0.71
D11 (Netherlands)	9.399772***	5.03	Cryic frigid	0.044433	1.15
D12 (Germany)	8.396953***	14.93	Permafrost	-0.120157	-1.21
D13 (Italy)	9.236173***	18.99	Cracking clays	0.001839	0.04
D14 (Spain)	9.162312***	22.99	Volcanic soils	-0.015798	-0.60
D15 (Greece)	8.942430*	3.29	Organic content	0.023412	0.60
D16 (Portugal)	8.910408***	3.89	Rock	0.063127**	2.47
D16 (Portugal)	8.910408***	3.89	λ-Clay top	6.049499	1.38
D17 (Sweden)	10.524742***	3.76	λ-Sandy top	0.596233***	3.10
Clayey topsoil	2.597846	1.37	λ-Irriper	1.354560***	7.17
Loamy topsoil	0.288363***	3.02	λ-Soilmoist	3.090652	2.99
Sandy topsoil	0.010818*	1.89	λ-Pop	0.088007***	4.32
Loamy subsoil	-0.047666	-1.07	λ-Alum	0.572417	1.25
Clay subsoil	-0.011116	-0.46	λ-Salinity	2.449942	0.98
Sandy subsoil	0.045021	0.79	λ-Arid	0.265039***	3.55
Observations	3579		Log Likelihood -2506	AIC 5095	
Schwarz Criterion	5355		Sigma 0.480817 (84.32)		

Finally, some have argued (see Baily, 1981; Ball, et al., 2013) that the sharp and unexpected rise in energy prices accelerated the rate of obsolescence of the stock of capital. These developments provided incentives for new capital investment, both to replace losses in the productive capacity of existing capital goods and to expand productive capacity.

Table 4. Purchasing Power Parities for Capital Input

Year	Belgium	Denmark	Germany	Greece	Spain	France	Ireland	Italy	Luxem-burg	NL	Portugal	Finland	Sweden	UK	Australia	Canada	US
1973	0.3694	1.1226	0.4729	0.0317	0.1349	0.2439	0.2238	0.1306	0.2420	0.3325	0.0261	0.1821	1.7446	0.2622	0.1987	0.4763	0.3982
1974	0.4489	2.3128	0.5438	0.0488	0.1751	0.2976	0.4119	0.1777	0.2313	0.4071	0.0323	0.2360	1.8470	0.3100	0.2210	0.5183	0.3957
1975	0.5044	1.9985	0.5063	0.0525	0.1374	0.3609	0.5679	0.1751	0.2489	0.4191	0.0307	0.2510	2.1469	0.3352	0.2377	0.5322	0.3180
1976	0.5196	1.8820	0.4297	0.0557	0.1447	0.3750	0.6913	0.1818	0.2783	0.4258	0.0295	0.3222	2.2568	0.3410	0.2611	0.5745	0.3198
1977	0.5024	2.1307	0.3809	0.0598	0.1478	0.3716	0.6465	0.1867	0.3457	0.4429	0.0387	0.4082	2.3488	0.2389	0.2857	0.5261	0.6382
1978	0.4631	3.0888	0.3573	0.0674	0.1932	0.3729	0.4883	0.1616	0.3369	0.4658	0.0572	0.5185	2.4710	0.1699	0.3116	0.6476	0.6261
1979	0.5379	4.3861	0.4854	0.0851	0.1875	0.3703	0.4502	0.1612	0.3555	0.4912	0.0619	0.6389	2.6408	0.1927	0.3384	0.8180	0.8068
1980	0.8746	5.3706	0.7587	0.1355	0.2414	0.4022	0.3613	0.2603	0.3853	0.5893	0.0773	0.8424	3.1318	0.2163	0.3705	1.2070	1.0504
1981	1.3018	6.4091	1.1612	0.2083	0.2016	0.5513	0.4592	0.3249	0.4304	0.7452	0.0994	1.0298	4.1094	0.2329	0.4748	1.8175	1.5687
1982	1.5685	8.5600	1.3125	0.2572	0.2584	0.7565	0.4966	0.3802	0.5387	0.8511	0.1613	1.0937	4.4651	0.2479	0.6389	1.6932	1.4567
1983	1.5018	7.0007	1.3009	0.2692	0.3805	0.8678	0.4571	0.3978	0.5512	0.8853	0.2788	1.0918	4.8669	0.2575	0.6119	1.3469	1.5944
1984	1.5521	6.7624	1.2933	0.2740	0.4248	0.8698	0.5067	0.4033	0.5881	0.8568	0.3813	1.2231	5.3077	0.3587	0.6322	1.8112	1.7026
1985	1.5711	5.8170	1.3571	0.2653	0.4078	0.8453	0.5217	0.4044	0.6268	0.9308	0.3354	1.3261	5.5877	0.4848	0.8547	1.8103	1.4510
1986	1.4370	6.9130	1.3325	0.3104	0.4434	0.8359	0.4715	0.4335	0.6361	1.1032	0.4394	1.3075	5.4117	0.4397	1.0839	1.6677	1.0227
1987	1.3886	10.2492	1.2884	0.3956	0.5014	0.9420	0.4573	0.4853	0.7115	1.2422	0.5615	1.4086	5.5079	0.5482	1.2838	1.8369	1.1822
1988	1.4574	10.2446	1.3649	0.4890	0.6716	1.0927	0.5437	0.5206	0.7599	1.4692	0.5624	1.5546	5.8608	0.5528	1.4115	1.7744	1.1610
1989	1.6620	11.4958	1.4926	0.6165	0.9312	1.2555	0.6862	0.7642	0.9008	1.6529	0.6886	1.7188	6.7018	0.5963	1.5425	1.9314	1.1666
1990	1.7433	11.7048	1.7136	0.7416	1.2082	1.5017	0.8147	0.8951	1.2142	1.8912	0.6839	1.9045	7.9246	0.7004	1.5525	2.2249	1.1947
1991	1.8415	10.3354	1.9369	1.0174	1.1323	1.6513	0.8492	0.9319	1.3091	2.1000	0.6544	1.9516	7.9383	0.4689	1.4782	2.1611	1.0525
1992	1.8889	11.7135	1.9782	1.1481	1.0725	1.7106	1.0635	1.1058	1.4943	2.0989	0.5632	1.6893	7.4480	0.4944	1.5088	2.0717	0.9008
1993	1.7076	11.5873	1.7169	1.3411	0.8668	1.5858	1.1477	1.2111	1.3396	1.9214	0.5044	1.4776	6.7426	0.5101	1.4901	2.1605	0.9107
1994	1.5757	13.2813	1.5730	1.4425	0.8503	1.5542	1.0452	1.2758	1.2367	1.8355	0.7171	1.4925	7.8994	0.6765	1.7254	2.3369	1.2606
1995	1.6477	14.0115	1.5966	1.4108	1.1984	1.6209	1.2627	1.4932	1.3088	1.8975	1.0250	1.5745	10.2766	1.0245	1.9768	2.5180	1.3040
1996	1.6007	14.9961	1.6306	1.3544	1.1606	1.5788	1.3157	1.5396	1.3344	1.8398	1.2746	1.0746	10.6355	1.1922	1.8991	2.2121	1.3302
1997	1.6637	14.1057	1.6594	1.0728	0.8342	1.5343	1.3323	1.3544	1.2287	1.8020	1.3789	1.2816	10.2796	1.0598	1.7544	2.2956	1.5826
1998	1.6537	13.2557	1.6188	1.0099	0.6031	1.4234	1.2388	0.8496	1.1493	1.4951	1.1179	1.1747	9.3982	0.9565	1.6249	2.5334	1.3845
1999	1.7631	13.4485	1.5783	1.0443	0.5065	1.4127	1.1454	0.8277	1.2795	1.6033	0.8464	1.0294	9.2229	0.9028	1.7064	3.1918	1.6914
2000	1.8191	14.7320	1.6896	0.9859	0.6036	1.4987	1.1279	1.0422	1.5089	1.9569	0.9187	1.3448	10.1150	0.9407	1.8264	2.8643	1.8229
2001	1.7818	14.5115	1.8268	0.8424	0.8277	1.5684	1.1027	1.0907	1.5308	1.8076	1.0313	1.3291	10.2142	1.0858	1.5803	2.0381	1.2260
2002	1.7109	14.5099	1.7731	0.9588	0.7810	1.6001	1.0220	0.9664	1.6316	1.6231	1.0510	1.2679	11.0949	1.1765	1.4986	2.7493	1.0818
2003	1.6002	13.7964	1.5878	0.9135	0.7502	1.5308	1.0282	0.7949	1.3874	1.4336	0.9705	1.3312	12.0589	0.9403	1.5711	2.7393	1.0277
2004	1.5730	14.9109	1.4779	0.9094	0.6298	1.4140	1.0280	0.7926	1.0926	1.4958	1.0233	1.6090	11.1983	0.9450	1.7015	1.8442	0.9033
2005	1.4415	14.5328	1.4852	0.9894	0.6762	1.2874	1.0572	0.8862	0.9052	1.6736	1.0332	1.5302	11.2986	0.9607	1.7404	1.3278	1.0000
2006	1.4305	14.0507	1.5197	0.9694	0.7186	1.2556	1.0278	1.0079	1.0382	1.6483	1.0995	1.6162	11.2882	0.9393	1.6628	1.7943	1.3582
2007	1.5290	16.5236	1.6471	1.1097	0.7685	1.3231	0.9842	1.1955	1.3293	1.8693	1.1562	1.7698	12.0735	1.1029	1.6807	2.1389	1.4102
2008	1.6575	18.4995	1.7708	1.2324	0.9496	1.3911	1.3710	1.2393	1.5071	2.2181	1.6364	1.6617	11.4960	1.2707	1.7290	1.5449	1.1146
2009	1.7164	15.0360	1.7107	1.0814	0.9540	1.4358	1.9362	1.2019	1.6081	2.1586	2.2640	1.5415	10.8713	0.8521	1.5673	1.7762	1.0020
2010	1.7886	16.4971	1.6101	1.6565	1.2591	1.3786	2.7973	1.2702	1.4222	2.2735	3.2715	1.5044	10.5479	1.0490	2.0926	2.8407	1.0522
2011	1.9361	11.7901	1.5623	2.4782	1.0794	1.3961	3.8919	2.0075	1.2007	2.4088	5.5386	1.6903	10.6628	0.7160	1.7733	1.7548	1.0352

Table 5. Prices of Capital Input Relative to U.S. in 2005

Year	Belgium	Denmark	Germany	Greece	Spain	France	Ireland	Italy	Luxem-burg	NL	Portugal	Finland	Sweden	UK	Australia	Canada	US
1973	0.3823	0.1856	0.3461	0.3650	0.3852	0.3589	0.4316	0.4337	0.2504	0.2621	0.2138	0.2833	0.3995	0.6425	0.2815	0.4763	0.3982
1974	0.4649	0.3795	0.4110	0.5543	0.5050	0.4055	0.7586	0.5290	0.2396	0.3337	0.2547	0.3718	0.4161	0.7247	0.3169	0.5299	0.3957
1975	0.5532	0.3478	0.4025	0.5578	0.3981	0.5523	0.9893	0.5192	0.2730	0.3652	0.2407	0.4057	0.5170	0.7415	0.3112	0.5232	0.3180
1976	0.5430	0.3113	0.3338	0.5202	0.3598	0.5147	0.9781	0.4229	0.2908	0.3549	0.1956	0.4958	0.5181	0.6127	0.3190	0.5827	0.3198
1977	0.5654	0.3549	0.3208	0.5531	0.3237	0.4960	0.8882	0.4097	0.3891	0.3977	0.2027	0.6023	0.5241	0.4167	0.3167	0.4947	0.6382
1978	0.5933	0.5601	0.3479	0.6249	0.4192	0.5420	0.7375	0.3687	0.4316	0.4744	0.2610	0.7488	0.5469	0.3257	0.3566	0.5677	0.6261
1979	0.7401	0.8337	0.5180	0.7825	0.4647	0.5710	0.7256	0.3758	0.4891	0.5396	0.2536	0.9751	0.6160	0.4081	0.3782	0.6983	0.8068
1980	1.2066	0.9529	0.8164	1.0835	0.5601	0.6243	0.5846	0.5885	0.5315	0.6532	0.3095	1.3428	0.7405	0.5026	0.4219	1.0323	1.0504
1981	1.4144	0.8997	1.0049	1.2807	0.3633	0.6655	0.5815	0.5535	0.4676	0.6581	0.3239	1.4189	0.8116	0.4681	0.5457	1.5160	1.5687
1982	1.3848	1.0273	1.0578	1.3119	0.3914	0.7551	0.5547	0.5444	0.4756	0.7024	0.4069	1.3490	0.7107	0.4331	0.6480	1.3724	1.4567
1983	1.1849	0.7655	0.9965	1.0418	0.4414	0.7469	0.4472	0.5071	0.4349	0.6835	0.5046	1.1654	0.6348	0.3903	0.5512	1.0929	1.5944
1984	1.0835	0.6530	0.8888	0.8282	0.4396	0.6528	0.4320	0.4445	0.4105	0.5884	0.5222	1.2100	0.6417	0.4771	0.5548	1.3986	1.7026
1985	1.0674	0.5490	0.9016	0.6545	0.3990	0.6171	0.4346	0.4101	0.4258	0.6176	0.3946	1.2722	0.6494	0.6222	0.5969	1.3258	1.4510
1986	1.2976	0.8544	1.2002	0.7556	0.5268	0.7916	0.4975	0.5630	0.5744	0.9923	0.5889	1.5335	0.7597	0.6445	0.7246	1.2002	1.0227
1987	1.5005	1.4989	1.4022	0.9951	0.6757	1.0283	0.5353	0.7268	0.7688	1.3517	0.8001	1.9044	0.8687	0.8959	0.8989	1.3853	1.1822
1988	1.5989	1.5222	1.5204	1.1738	0.9581	1.2037	0.6521	0.7750	0.8337	1.6385	0.7828	2.2050	0.9565	0.9833	1.1028	1.4418	1.1610
1989	1.7015	1.5739	1.5541	1.2930	1.3099	1.2923	0.7663	1.0795	0.9222	1.7191	0.8774	2.3797	1.0395	0.9757	1.2197	1.6313	1.1666
1990	2.1044	1.8937	2.0745	1.5941	1.9723	1.8093	1.0612	1.4468	1.4658	2.2897	0.9618	2.9583	1.3389	1.2436	1.2119	1.9068	1.1947
1991	2.1754	1.6166	2.2837	1.9008	1.8140	1.9201	1.0689	1.4554	1.5464	2.4757	0.9083	2.8688	1.3127	0.8269	1.1515	1.8863	1.0525
1992	2.3701	1.9411	2.4760	2.0496	1.7411	2.1185	1.4239	1.7360	1.8750	2.6293	0.8371	2.2364	1.2789	0.8678	1.1081	1.7140	0.9008
1993	1.9911	1.7890	2.0314	1.9916	1.1340	1.8373	1.3228	1.4933	1.5620	2.2803	0.6294	1.5355	0.8663	0.7651	1.0133	1.6747	0.9107
1994	1.8999	2.0895	1.8965	2.0268	1.0568	1.8378	1.2307	1.5333	1.4912	2.2235	0.8664	1.6962	1.0238	1.0353	1.2615	1.7112	1.2606
1995	2.2547	2.5007	2.1794	2.0740	1.6000	2.1314	1.5937	1.7753	1.7910	2.6056	1.3703	2.1374	1.4407	1.6167	1.4654	1.8347	1.3040
1996	2.0855	2.5864	2.1191	1.9164	1.5250	2.0248	1.6574	1.9325	1.7386	2.4052	1.6569	1.3908	1.5860	1.8601	1.4861	1.6224	1.3302
1997	1.8760	2.1365	1.8721	1.3385	0.9482	1.7251	1.5899	1.5404	1.3855	2.0361	1.5775	1.4674	1.3464	1.7350	1.3021	1.6579	1.5826
1998	1.8378	1.9781	1.7987	1.1648	0.6718	1.5831	1.3887	0.9474	1.2773	1.6615	1.2437	1.3065	1.1822	1.5840	1.0208	1.7078	1.3845
1999	1.8783	1.9268	1.6818	1.1634	0.5396	1.5049	1.2202	0.8817	1.3631	1.7080	0.9017	1.0966	1.1162	1.4607	1.1010	2.1483	1.6914
2000	1.6762	1.8212	1.5571	0.9182	0.5562	1.3810	1.0386	0.9603	1.3904	1.8033	0.8465	1.2381	1.1040	1.4233	1.0589	1.9287	1.8229
2001	1.5942	1.7422	1.6357	0.7537	0.7405	1.4032	0.9868	0.9758	1.3696	1.6173	0.9227	1.1892	0.9889	1.5631	0.8174	1.3159	1.2260
2002	1.6120	1.8405	1.6706	0.9035	0.7359	1.5076	0.9631	0.9106	1.5374	1.5293	0.9903	1.1947	1.1394	1.7633	0.8142	1.7519	1.0818
2003	1.8074	2.0976	1.7934	1.0318	0.8474	1.7291	1.1616	0.8979	1.5670	1.6192	1.0962	1.5036	1.4913	1.5352	1.0189	1.9551	1.0277
2004	1.9544	2.4900	1.8362	1.1299	0.7826	1.7568	1.2774	0.9847	1.3575	1.8585	1.2715	1.9991	1.5238	1.7302	1.2514	1.4175	0.9033
2005	1.7914	2.4238	1.8456	1.2294	0.8402	1.5997	1.3138	1.1011	1.1249	2.0796	1.2839	1.9015	1.5119	1.7468	1.3291	1.0958	1.0000
2006	1.7952	2.3643	1.9070	1.2165	0.9017	1.5756	1.2898	1.2648	1.3028	2.0683	1.3797	2.0281	1.5299	1.7283	1.2522	1.5818	1.3582
2007	2.0927	3.0354	2.2543	1.5188	1.0519	1.8109	1.3470	1.6362	1.8194	2.5584	1.5824	2.4222	1.7864	2.2068	1.4064	1.9914	1.4102
2008	2.4279	3.6311	2.5940	1.8052	1.3910	2.0377	2.0083	1.8153	2.2076	3.2491	2.3970	2.4341	1.7442	2.3360	1.4503	1.4478	1.1146
2009	2.3844	2.8060	2.3765	1.5022	1.3253	1.9946	2.6897	1.6697	2.2339	2.9987	3.1451	2.1414	1.4204	1.3274	1.2223	1.5539	1.0020
2010	2.3688	2.9133	2.1324	2.1939	1.6676	1.8258	3.7048	1.6823	1.8836	3.0111	4.3328	1.9925	1.4634	1.6209	1.9162	2.7575	1.0522
2011	2.6914	2.2006	2.1719	3.4451	1.5005	1.9408	5.4103	2.7907	1.6691	3.3485	7.6994	2.3498	1.6421	1.1472	1.8292	1.7734	1.0352

Table 6. Capital Input (Millions of 2005 U.S. Dollars)

Year	Belgium	Denmark	Germany	Greece	Spain	France	Ireland	Italy	Luxem-burg	NL	Portugal	Finland	Sweden	UK	Australia	Canada	US
1973	648	1132	11382	1814	5039	7521	970	9989	89	1286	714	1169	1108	4436	5917	2704	33147
1974	678	1191	11488	1846	5097	7811	999	10099	91	1383	762	1174	1094	4497	6102	2861	34002
1975	705	1252	11511	1881	5088	8087	985	10119	93	1472	820	1184	1091	4583	6265	3048	35055
1976	710	1319	11554	1950	5119	8297	990	10225	94	1526	884	1197	1103	4587	6441	3294	35782
1977	720	1394	11650	2010	5165	8511	1010	10413	94	1589	932	1210	1120	4538	6663	3602	35424
1978	737	1445	11839	2067	5226	8674	1032	10644	92	1706	986	1219	1121	4651	6856	3809	35942
1979	763	1497	11773	2083	5328	8890	1063	10935	93	1848	1020	1224	1111	4698	7067	3998	36580
1980	769	1541	11850	2154	5437	9095	1097	10943	93	1976	1060	1232	1101	4725	7341	4187	37144
1981	765	1550	11866	2215	5686	9239	1122	11065	93	2038	1095	1250	1077	4683	7384	4269	37027
1982	758	1540	11809	2237	5796	9345	1154	11103	92	2082	1121	1266	1056	4663	7534	4292	36651
1983	755	1528	11751	2261	5865	9460	1169	11123	93	2127	1121	1290	1041	4693	7653	4249	35894
1984	749	1525	11745	2260	5927	9521	1170	11118	94	2195	1120	1286	1029	4682	7779	4158	35148
1985	744	1526	11702	2254	5984	9568	1168	11116	93	2224	1108	1323	1024	4751	7909	4077	34360
1986	738	1540	11659	2268	5987	9577	1160	11113	92	2249	1092	1332	1007	4783	7983	3929	33169
1987	736	1551	11599	2183	6018	9532	1152	11108	90	2254	1088	1325	983	4756	8005	3769	31857
1988	734	1550	11535	2077	6029	9492	1139	11112	89	2271	1103	1332	963	4731	8026	3614	30955
1989	730	1539	11501	1994	5992	9476	1133	11151	88	2282	1164	1337	951	4691	8090	3462	30170
1990	726	1545	12278	1935	5929	9525	1141	11177	88	2305	1209	1321	946	4672	8159	3329	29579
1991	724	1543	12185	1865	5815	9547	1148	11163	88	2325	1193	1349	933	4666	8172	3197	29110
1992	715	1533	12183	1803	5749	9540	1146	11128	89	2344	1175	1339	907	4605	8142	3086	28492
1993	718	1492	12211	1754	5610	9486	1142	11067	89	2365	1162	1293	878	4563	8121	2989	27798
1994	711	1444	12147	1686	5466	9404	1137	10963	89	2348	1127	1256	849	4572	8077	2951	27254
1995	699	1446	12044	1629	5339	9357	1145	10894	89	2327	1104	1229	833	4591	8058	2912	26863
1996	690	1453	11939	1589	5259	9355	1148	10823	87	2317	1080	1198	819	4626	8100	2889	26467
1997	684	1466	11855	1561	5261	9393	1167	10776	87	2297	1066	1189	807	4642	8147	2863	26224
1998	681	1475	11788	1544	5250	9456	1168	10759	86	2296	1057	1192	798	4623	8220	2890	26088
1999	679	1460	11645	1544	5263	9549	1172	10744	85	2294	1047	1192	789	4556	8348	2929	26014
2000	678	1459	11587	1565	5221	9650	1172	10734	83	2306	1050	1199	785	4450	8454	2920	25845
2001	677	1471	11554	1609	5210	9715	1169	10760	82	2311	1052	1202	795	4420	8533	2915	25710
2002	679	1484	11481	1609	5207	9761	1164	10769	81	2335	1054	1206	803	4388	8598	2888	25718
2003	682	1486	11475	1642	5227	9788	1160	10879	80	2330	1054	1215	815	4345	8683	2882	25759
2004	684	1495	11410	1694	5270	9826	1153	10973	81	2335	1053	1227	823	4324	8816	2876	26048
2005	686	1514	11346	1727	5348	9888	1153	11130	83	2332	1056	1225	831	4327	8922	2903	26590
2006	690	1525	11199	1785	5336	9932	1150	11204	83	2324	1052	1240	833	4349	9054	2864	26714
2007	700	1527	11138	1820	5369	9981	1157	11256	83	2331	1047	1237	837	4331	9202	2829	26552
2008	721	1557	11115	1890	5436	10086	1199	11259	83	2373	1045	1230	849	4361	9295	2871	26695
2009	723	1560	11184	1965	5500	10227	1226	11386	84	2414	1043	1229	867	4373	9480	2903	27290
2010	743	1554	11081	1972	5562	10250	1211	11337	85	2411	1039	1248	873	4411	9706	2927	27217
2011	759	1544	11019	1981	5583	10184	1198	11272	86	2418	1036	1232	877	4459	9943	2987	27286

The conditions that led to expansion during the 1970s came to an end in the 1980s, as interest rates soared and the global economy went into recession. Growth in capital input slowed dramatically in most countries over the following two decades. By the early 2000s, the level of capital input in United States agriculture had fallen by a third.[12] Growth in capital input recovered somewhat during the 2000s. Still, the European countries, Canada and Australia all posted gains in relative levels of capital input over this period of time.

4. Land *versus* Depreciable Assets

We analyzed the structure of aggregate capital input in agriculture for the seventeen countries by decomposing it into two components: capital services from land and those from depreciable assets. Distinguishing between land and depreciable assets allows us to separate the role of environmental and natural resource endowments (i.e. climate conditions and soil quality) from that of physical capital and its embodied technology in affecting agricultural production.[13]

Over time, capital services obtained from land decreased while those obtained from depreciable assets increased in most countries. Between 1973 and 2011, capital services from land at the 2005 constant US price declined in sixteen of the seventeen countries. Greece was the exception. In land intensive countries such as Australia, Canada and the United States, capital services from land fell more quickly than in the EU countries.

In contrast, capital services from depreciable assets (including transportation vehicles, machinery and plant and non-dwelling buildings and structures) increased over the same period of time in twelve of the seventeen countries. Exceptions were the United States, Germany, Greece, Sweden and Luxembourg.

Differences in the growth of land and depreciable capital inputs over time has altered the structure of the capital input in the sixteen OECD countries relative to the United States. Figure 4 presents relative ratios of the depreciable capital input to the land input. Because the interest rate plays the same role in determining the trend of services derived from depreciable capital and land, taking the ratio between the depreciable capital input and the land input effectively cancels out interest rate effects. The movement of the ratio over time is therefore more likely to be driven by changes in the stocks of these types of capital.

Between 1973 and 2011 most EU countries increased the ratio of depreciable capital to land relative to the United States. Greece was the exception. By 2011, the ratio of depreciable capital to land was higher in thirteen of the fourteen EU countries (except the United Kingdom), even though some of these countries (Belgium, Denmark, Spain, France, Ireland and Portugal) initially had lower levels of this ratio.

Outside the EU, Canada and Australia initially had lower relative ratios of depreciable capital to land, partly because these countries had more abundant land resources. However, the difference between these countries and the United States has narrowed over time. In particular, Australia increased the relative ratio of depreciable capital to land five-fold between 1973 and 2011.

Overall, our estimates reveal that increases in relative capital use on farms in OECD countries

[12] Ball, et al., (2013) show that purchased machine services exhibited a counter-cyclical pattern, suggesting the substitution of purchased machine services for own capital input.

[13] Splitting between land and depreciable assets also reflects the concern that it will take much longer time for the price (opportunity cost) of land than depreciable assets for agricultural production to be equalized across countries.

were accompanied by change in the structure of the capital input, away from land and towards depreciable capital items. The increased use of depreciable capital has resulted in capital deepening with respect to land. Similar to using differences in land per unit of labour to explain differences in labour productivity between countries (Gollin, et al. 2014a), differences in depreciable capital per unit of land could be used to understand the implications for agricultural productivity growth of adopting land-augmented technologies.

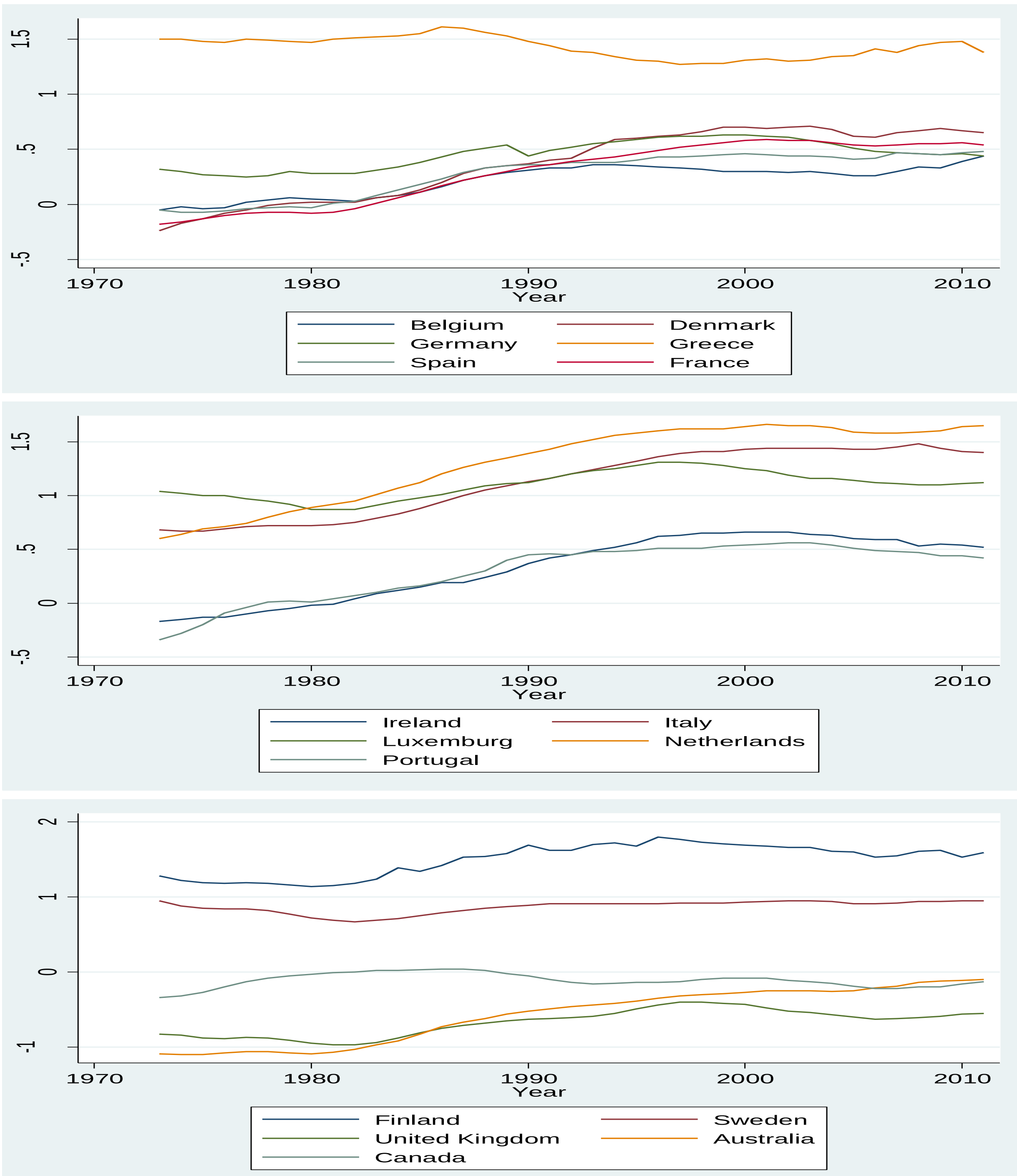


Figure 4. Relative ratio of depreciable capital input to land input (compared to the US).

5. Summary and Conclusions

This paper provides a farm-sector comparison of relative levels of capital input among seventeen OECD countries over the period 1973-2011. In doing so, we construct the capital stocks by asset type using the perpetual inventory method and distinguish between land and depreciable assets. Then, estimates of capital services is made by means of capital rental prices. For depreciable assets, implicit rental prices for each asset type are based on the correspondence between the purchase price of the asset and the discounted value of future service flows derived from that asset and adjusted for the purchasing power parity. For land, the hedonic method is also employed to account for the quality difference (caused by environmental factors such as soil quality and rainfall) between countries.

Our estimates show that relative prices of capital input on farm in the sixteen OECD countries relative to the United States fluctuated over the sample period between 1973 and 2011, which reflected the cyclically changes in rates of inflation and the strengths of the dollar on foreign exchange and bond markets in the United States.

In terms of relative levels of capital input, fifteen of the sixteen countries in the comparison had higher levels of capital input relative to the United States in 2011 than at the beginning of the sample period in 1973. The Netherlands exhibited the largest increase in the relative level of capital input, followed by Australia. Both countries saw relative capital input more than double between 1973 and 2011. Sweden, by contrast, experienced a decline in relative capital input.

Finally, our estimates reveal that increases in relative capital use on farms in OECD countries were accompanied by change in the structure of the capital input, away from land and towards depreciable capital items. This change reflects the adoption of land-augmented technology which could be an independent driver of differences in agricultural productivity between countries.

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