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TECHNOLOGY CATCH-UP IN AGRICULTURE AMONG ADVANCED ECONOMIES

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Technology Catch-Up in Agriculture among Advanced Economies

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ABSTRACT

The article tests the hypothesis of convergence in relative levels of total factor productivity across seventeen member countries of the Organization for Economic Cooperation and Development and tries to identify factors that affect the speed of convergence. Using a panel data model, we investigate the role of relative factor intensities (i.e. embodiment) and assess the impact of fluctuations in aggregate economic activity (i.e., the business cycle). We also consider the role of human capital spillovers and agricultural policy differences such as the Common Agricultural Policy of the European Union. We use a two-step difference Generalised Method of Moments estimator to quantify the contributions of each of these factors. We find evidence of convergence in productivity levels across the different phases of the business cycle. However, the speed of convergence was higher during contractions (negative output gap) than along expansions. Results show that the speed of convergence among the European countries during the economic slowdown is slower than in Australia, Canada and the United States. Finally, we found significant spillovers from investment in human capital and the productivity of the national economy leading to more rapid productivity growth.

Keywords: Total Factor Productivity, business cycle, productivity convergence, OECD Agriculture, Generalised Method of Moments.

JEL classifications: Q16, Q17

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Introduction

The paper discusses why countries with relatively low initial levels of total factor productivity (TFP) may show faster growth than the technology leaders or catch-up". We utilise a panel data model to identify factors that may influence the speed of convergence. We contrast the role of capital embodiment, fluctuations in aggregate economic activity (the business cycle), human capital spillovers, and certain agricultural policies, like the Common Agricultural Policy (CAP), in productivity convergence for seventeen OECD countries[5].

McCunn and Huffman (2000) found evidence of convergence in levels of agricultural TFP (i.e., β-convergence) across the US States. They rejected the hypothesis of declining cross-sectional dispersion (i.e., σ-convergence). Ball, Hallahan, and Nehring (2004) also found evidence of convergence in TFP levels in a panel of US States after controlling for differences in relative factor intensities (i.e., embodiment). Comparisons within the US States show that States with lower initial levels of TFP achieve faster growth.

In this paper, we examine how the business cycle affects technology catch-up. Following the section on motivation, we explore the relationship between the business cycle and convergence. After discussing the data used, and the decomposition of growth into input and TFP components, we present the comparative TFP growth rates among 17 OECD countries over the period 1973 to 2011. Finally, we present the models of

[5] Australia, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom, United States.

convergence and the empirical results regarding catching–up, embodiment, and the business cycle.

Motivation

The objective of this paper is to test the convergence hypothesis using panel data for 17 OECD countries. We then examine the speed of convergence and whether the convergence is transitory or permanent in nature. Convergence affects regional disparities in income and has important implications for the design of the agricultural policy.

Since slowdowns in the rates of growth of the TFP leaders may affect growth rates of the "lagging countries", we also include the national economy TFP spillovers in our convergence model. We use a convergence model of TFP, not only to assess beta-convergence in three different continents but also to identify the main drivers of agricultural TFP change.

Convergence definitions

The neoclassical growth model (Solow, 1956), assumes that production is subject to diminishing returns to capital. This implies, assuming absolute convergence, that economies may converge to the same steady-state. However, for this to happen, all countries would have to share the same steady-state, something that does not happen due to the individual characteristics of each country (soil, climate, institutions, preferences, laws, and other idiosyncratic characteristics of each agriculture) that make each country's agriculture trend to different steady states. Therefore, it is much more realistic to think in terms of conditional convergence, which takes into account the different stationary states to which each country or region trends.

Thus, according to the predictions of this model, investments in innovation accelerate the rate of productivity growth, with technology spillovers allowing less productive farmers to "catch up." If technology spillovers are embodied in physical capital intensities which are not properly priced, investment pattern and its related technology spillover matter for the catch-up process (Whelan 2007). Moreover, asymmetric shocks affect the cyclical fluctuations in economic activity and alter the speed of convergence (Escribano and Stucchi, 2008; Ball et al. 2014).

Following Barro and Sala-i-Martin (1992; 1995) there is β-convergence if countries with lower levels of productivity tend to grow faster than the technology leaders and σ-convergence if the dispersion of their relative TFP levels tends to decrease over time.
It follows that β-convergence is a necessary but not a sufficient condition for σ-convergence (Quah, 1993). An important implication of this result is that income inequality across countries or regions may persist due to shocks (e.g., cyclical fluctuations in economic activity) that tend to increase dispersion.

Two alternative explanations have been proposed in the literature to explain why convergence patterns may be related to the business cycle. The first is based on the pro-cyclical nature of the innovation process (Geroski and Walters, 1995; Basu and Fernald, 2001), and the time lags between technological innovations and diffusion processes (Jovanovic and McDonald, 1994).

According to this argument, productivity leaders tend to innovate more during periods of expansion in response to positive demand shocks. However, due to the existence of informational barriers, productivity followers, who tend to learn by imitation, postpone the adoption of innovations made by the technology leaders until economic downturns. Indeed, there is a second explanation based on the relation between competition and productivity. Productivity followers have more incentive to reduce their costs during downturns when adverse demand shocks increase the probability that these firms will exit the industry (Escribano and Stucchi, 2008).

Taken together, these arguments point to faster rates of convergence during contractions in economic activity and slower rates of convergence, or even divergence, during periods of expansion. The latter is consistent with the theoretical models of competition that predict that the follower's productivity growth is below the rate of the leader's during downturns (Bloom, N., and Van Reenen J., 2007).

Model specification

We follow the econometric approach of Escribano and Stucchi (2008) previously applied to test convergence between the industrial sector firms. First, we test the catch-up hypothesis using a model that ignores the business cycle (i.e., the benchmark model).

$$\log\left(\frac{TFP_{it}}{TFP_{it-1}}\right) = \beta_0 + \beta_1 \log(TFP_{it-1}) + \beta_2 \log(X_{it}) + \varphi_i + \tau_t + \varepsilon_{it}$$

Equation 1

The dependent variable is the $\log\left(\frac{TFP_{it}}{TFP_{it-1}}\right)$ the productivity rate of growth

- TFP_{it-1} is the lag(-1) of the TFP, the initial level of TFP
- β_0 is the constant

- β_1 is the coefficient on the initial level, negative if there is convergence
- β_2 coefficient of the control variables vector X_{it}
- φ_i are the non-country observed specific effects
- τ_t time-specific country effects
- ε_{it} i.i.d. residuals
- $log(X_{it})$is the log control variables vector:
- β_2 is the coefficient of the control variable matrix
- K/L capital (excluding land) per labour unit, which captures the effect of technological innovations embodied in capital
- K/A capital per quantity of land, which reflects the capital endowment per unit of arable land.

Other 'control variables' include investment in human capital, **hc:** Years of schooling to capture possible technology spillovers from human capital (Parman, 2012), and the level of productivity of the national economy, **nTFP** (Feenstra et al., 2015). We also include the control variable "Output gap" (Og) of the economy to control for phases of the business cycle. The output gap is defined as the difference between the actual and the potential levels of output of an economy, expressed as a percentage of the potential output. For that purpose, potential output is commonly defined as the level of output that can be achieved when the factors of production are utilised at non-inflationary levels. In fact, the output gap is an indicator commonly used to summarise the overall amount of slack present in the economy and is currently used by the US Federal Reserve (FED) and the European Central Bank (ECB) (See ECB, 2005). First, we examine the impacts of the business cycle on TFP convergence. To determine the possible impacts of the business cycle on the convergence process, we check how the **convergence rate β_1** changes across different phases of the business cycle. Testing for β-convergence is equivalent to testing H_0: if $\beta_1>0$ (i.e., no β-convergence) against H_1: $\beta_1<0$ (i.e., β-convergence), where β_1 is the rate of convergence.

Growth accounting and measurement of TFP: Data

This section explains the growth accounting approach using available data from the national accounts systems and the Economic Accounts of Agriculture (EAA) at Eurostat for the European Union Member States (Ball et al. 2016; ABARES, 2017; EAA Eurostat, 2019; Statistics Canada, 2019).

Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Department of Agriculture and Water Resources recently published detailed production account data (including both prices and quantities of various inputs and outputs based on the ABS release and the farm census/farm surveys) for the farm sector since 1949 (Sheng et al. 2018). Following Ball et al. (2016), we have aligned these accounting data to be consistent with US and EU STAT accounts for the cross-country comparison. Statistics Canada publishes industry production accounts based on the input-output tables from the national accounts (Baldwin and Harchauoui, 2002). The program is ongoing (see Statistics Canada, 2019), and these data are updated regularly (Cahill, S. and Rich, T., 2012).

To calculate TFP, we revise and update the series of Ball et al. (2010) by constructing country-specific aggregates of output and capital, labour, and materials inputs as Tornqvist or translog indexes over detailed output and input accounts.

Growth accounting and measurement of TFP

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Output and intermediate inputs

The development of a measure of output begins with disaggregated data on prices and quantities of agricultural goods. For each category of output, the quantity includes the quantities sold off the farm, additions to inventory, and quantities consumed in farm households during the calendar year. The corresponding price reflects the value of that output to the producer as subsidies are added, and indirect taxes are subtracted from market values.

The measure of output also includes goods and services of non-agricultural (or secondary) activities when these activities cannot be distinguished from the primary agricultural activity.

Two types of secondary activities are distinguished. The first represents a continuation of the agricultural activity, such as the processing and packaging of agricultural products on the farm, while services relating to agricultural production, such as machine services for hire, are typical of the second.

Translog indexes of output are formed by aggregating over agricultural goods output and the output of goods and services of inseparable secondary activities using revenue-share weights based on shadow prices.

Intermediate inputs consist of goods and services used in production during the calendar year, whether purchased from outside the farm sector or from beginning inventories. We assume that intermediate goods produced and consumed within the farm (i.e., grain for livestock feeding) are from beginning stocks. It follows that the measure of output, as defined above, is equal to gross production.

Measures of intermediate inputs are formed as translog indexes over a set of goods and services. Price and quantity data corresponding to purchases of feed and seed are available and directly enter the calculation of intermediate goods[6]. Purchases of livestock are recorded as additions to the stock of "goods in progress" and hence are excluded from intermediate inputs. Similarly, cash receipts are net of livestock purchases. Data on expenditures on petroleum fuels, natural gas, and electricity at current prices are also available. The corresponding quantity measure for each energy source is calculated implicitly as the ratio of expenditures and price. Fertilisers and pesticides also are important intermediate inputs, but their data require adjustment since these inputs have undergone significant changes in input quality over the study period. Since input price and quantity series used in a study of productivity must be denominated in constant-efficiency units, price indexes for fertilisers and pesticides are constructed using hedonic techniques. A price index for fertilisers is estimated by regressing the prices of single nutrient and multi-grade fertiliser materials on the proportion of nutrients contained in the materials, prices of pesticides are regressed on physical characteristics such as toxicity, persistence in the environment, and leaching potential.

[6]Feedgrains drawn from beginning stocks are priced at their opportunity cost.

We also construct indices of purchased services. To decompose expenditures for contract labour services into price and quantity components, we estimate a hedonic wage function where hourly earnings are expressed as a function of demographic characteristics including sex, age, education, and experience, as well as legal status and type of employment (hired versus contract labourers) (See Wang et al. (2013) for further discussion).

Purchased machine services are a close substitute for own capital input. Therefore, we construct the implicit quantity of purchased machine services as the ratio of expenditures to an index of rental prices of agricultural machinery. Translog indexes of intermediate input are then constructed by weighting the growth rates of each category of intermediate inputs described above by their value shares in the overall value of intermediate input.

To measure relative levels of output and intermediate input, we construct multilateral translog price indexes (see Caves, Christensen, and Diewert, 1982; Ball et al., 2010). A price index that converts the ratio of nominal values between two countries into a measure of real output or input is referred to as a purchasing power parity (PPP) of the currencies of the two countries. The result is panel data that can be used for both cross-section and time series analysis.

Capital inputThe measurement of capital input begins with data on the stock of capital in each country for each component of capital input, based on investments in constant prices. For depreciable assets including transportation equipment, other machinery, and structures, the capital stocks are constructed as a weighted sum of all past investments.

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 shortcoming of 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. However, little information is available on the actual service lives of assets. In this paper, we adopt a set of assumptions required to model variations in service lives, and once these service lives are determined, the rate of capacity depreciation or decline in the efficiency of the capital stock is obtained.

We represent depreciable capital stock at the end of each period, K_τ, as the sum of past investments, each weighted by its relative efficiency, d_τ:

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

Equation 2

We normalise initial efficiency d_0 at unity and assume that relative efficiency decreases with asset age so that:

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

Equation 3

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

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

Equation 4

The decline in the efficiency of capital goods gives rise to needs for replacement in order to maintain the productive capacity of the capital stock.

The proportion of a given investment to be replaced at age, m_τ, is equal to the decline in efficiency from age τ^{-1} to age τ:

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

Equation 5

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

Replacement requirements,

$$\boldsymbol{R_t} = \sum_{\tau=1}^{\infty} \boldsymbol{m_\tau I_{t-\tau}}$$

Equation 6

R_t, are represented as a weighted sum of past investments

where the weights are the mortality rates.

To estimate replacement, we must introduce an explicit description of the decline in efficiency. The efficiency function, ***d***, may be expressed in terms of two parameters, the service life of the asset, L, and a curvature or decay parameter, **β**. One possible form for the efficiency function is given by:

$$d_\tau = (L - \tau)/(L - \beta\tau), 0 \le \tau \le L$$
$$d_\tau = 0, \tau \ge L$$

Equation 7

This function is a form of a rectangular hyperbola that provides a general model incorporating several types of depreciation as special cases. The value of **β** is restricted only to values less than or equal to one. For values of **β** greater than zero, the function *d* approaches zero at an increasing rate. For values less than zero, ***d*** approaches zero at a decreasing rate.

Two studies (Penson, Hughes, and Nelson, 1977; Romain, Penson, and Lambert, 1987) provide evidence that the decline in efficiency occurs more rapidly in the later years of service, corresponding to a value of **β** in the zero-one interval. The efficiency of a structure declines very slowly over most of its service life until a point is reached where the cost of repairs exceeds the increased service derived from the repairs, at which point the structure is allowed to depreciate rapidly (β=0.75). The decay parameter for durable equipment (β=0.5) assumes that its decline in efficiency is more uniformly distributed over the asset's service life.

The other critical variable in the efficiency function is asset lifetime L. For each asset type, the service life L is a random variable reflecting quality differences, maintenance schedules, etc. There exists some mean service life $\bar{L}$ (bar over L indicates "mean") around which there is a distribution of the actual service lives of the assets in the group. We assume that this distribution may be accurately depicted by the standard normal distribution truncated at points two standard deviations before and after the mean service life.

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 characterised by a decaying geometric series. The remaining task is to generalise the representation of the rental price to allow for any pattern of capacity depreciation. To accomplish this task, we draw on the investment demand literature (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 smaximise the present value of the firm. Firms will add to the capital stock so long as the present value of the net revenue generated by an additional unit of capital exceeds the purchase price of the asset:

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

Equation 8

To maximise net present value, firms will continue to add to the capital stock until this equation holds as an equality:

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

Equation 9

where c is the implicit rental price of capital.

The above expression can be simplified as follows. Let *F* denote the present value of the stream of capacity depreciation on one unit of capital, that is:

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

Equation 10

It can be shown that

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

Equation 11

so that

$$c = \frac{r \ w}{(1-F)}$$

Equation 12

The real rate of return *r* in the above expression is calculated as the nominal yield on government bonds of fixed maturity less the rate of price inflation as measured by the implicit deflator for gross domestic product. An ex-ante rate is obtained by expressing inflation as an ARIMA process. Implicit rental prices c are then calculated for each asset type in each country using the expected real rate of return.

Although we estimate the decline in the efficiency of capital goods for each component of capital input separately for each country, we assume that the relative efficiency of new capital goods is the same in each country. The appropriate purchasing power parity for new capital goods is the purchasing power parity for the corresponding component of investment good output (OECD, 1999, p. 162). To obtain the purchasing power parity for capital input, we multiply the purchasing power parity for investment goods for any country by the ratio of the price of capital input in that country relative to the United States.

Land

To estimate the stock of land in each country, we first construct translog price indexes of land in agriculture. The stock of land is then constructed implicitly as the ratio of the value of agricultural land in each country to the corresponding price index. The rental price of land is obtained using Equation 12, assuming zero replacement.

Spatial differences in land characteristics or quality prevent the direct comparison of observed prices across countries. To account for these differences, indexes of relative prices of land are constructed using hedonic methods in which a good is viewed as a bundle of characteristics that contribute to the productivity derived from its use. According to the hedonic framework, the price of a good represents the valuation of the characteristics that are bundled in it, and each characteristic is valued by its implicit price (Rosen 1974). These prices are not observed directly and must be estimated from the hedonic price function.

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=w(X, D), where W represents the price of land, X is a vector of characteristics, and D is a vector of country dummy variables. Sanchez et al. (2003) introduced a soil classification system that can be used to identify those attributes that are relevant for crop production. The attributes most common in major agricultural areas in the European countries and Australia are loamy topsoils and moisture stress.

In areas subject to moisture stress, agriculture is not possible without irrigation. Hence, irrigation (i.e., the percentage of cropland irrigated) is included as a separate variable. We also include an interaction term between moisture stress and irrigation. Because irrigation mitigates the negative impact of acidity on plant growth, the interaction between irrigation and soil acidity is included in the vector of characteristics.

In addition to environmental attributes, we also include a "population accessibility" score for each region in each country. These indexes are constructed using a gravity model of urban development, which provides a measure of accessibility to population concentrations. The index increases as population increases and/or distance from the population centres decreases.

Labour

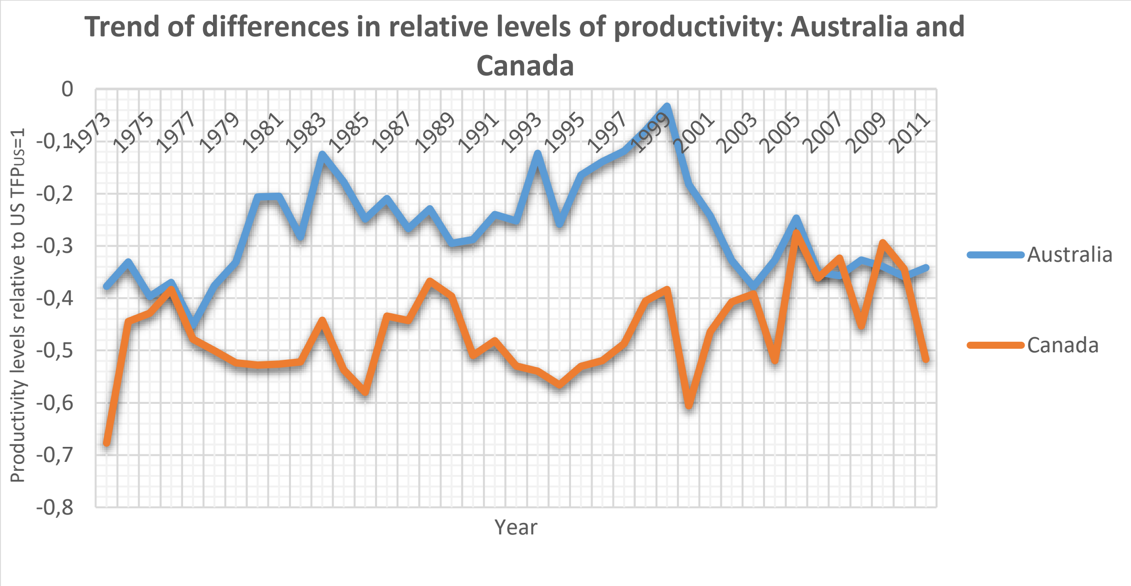
Data on labour input in agriculture consist of hours worked disaggregated by hired and self-employed and unpaid family workers (Eurostat, 2000). Compensation of hired farmworkers is defined as the average hourly wage plus the value of perquisites and employer contributions to social insurance.

The compensation of self-employed workers is not directly observable. These data are derived using the accounting identity where the value of the total product is equal to total factor outlay. Historical TFP rate versus post-crisis acceleration This section provides a brief overview of patterns of TFP growth. Over the entire study period, the United States continues to be the leader in TFP level (See Figures 1 and 2) but not in the average annual rate of growth. Moreover, for the United States, the average rate of growth from 1973 to 2011 is below the average of the fourteen European Union and the seventeen OECD countries (Figure 3).

Australia was closing the gap in relative levels of productivity with the United States until 1999 (Figure 1). However, after the "millennium drought", Australia's relative level of productivity fell to the level of Canada despite achieving a higher average growth rate than the United States between 1973 and 2011 (Figure 1) [7].

[7] The US present the the highest level of TFP during the period so we normalise the level of the log productivity of the rest of the countries, been $TFP_{US} = 0$. The values of each country represent the relative level of productivity each year to visualize if the gap with the leader is closing or widening. For instance, Australia was closing the gap until reach -0.03 or a gap of 3% with the US level of productivity in 1999. Moreover after the drought of the century the Australian gap widen until -0.39 or a gap of 39% with the leader.

Figure 1. Trends of differences in relative levels of productivity. Australia and Canada versus the United States (TFP_{US} =0)[8]



Source: Own elaboration

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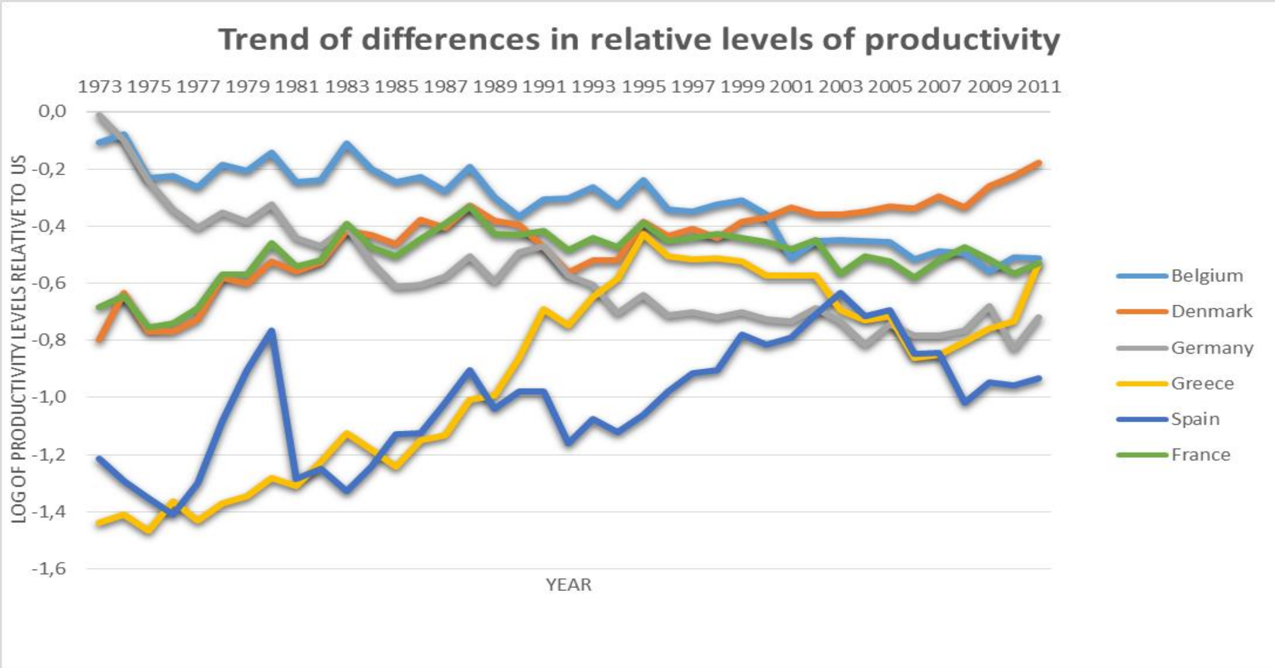
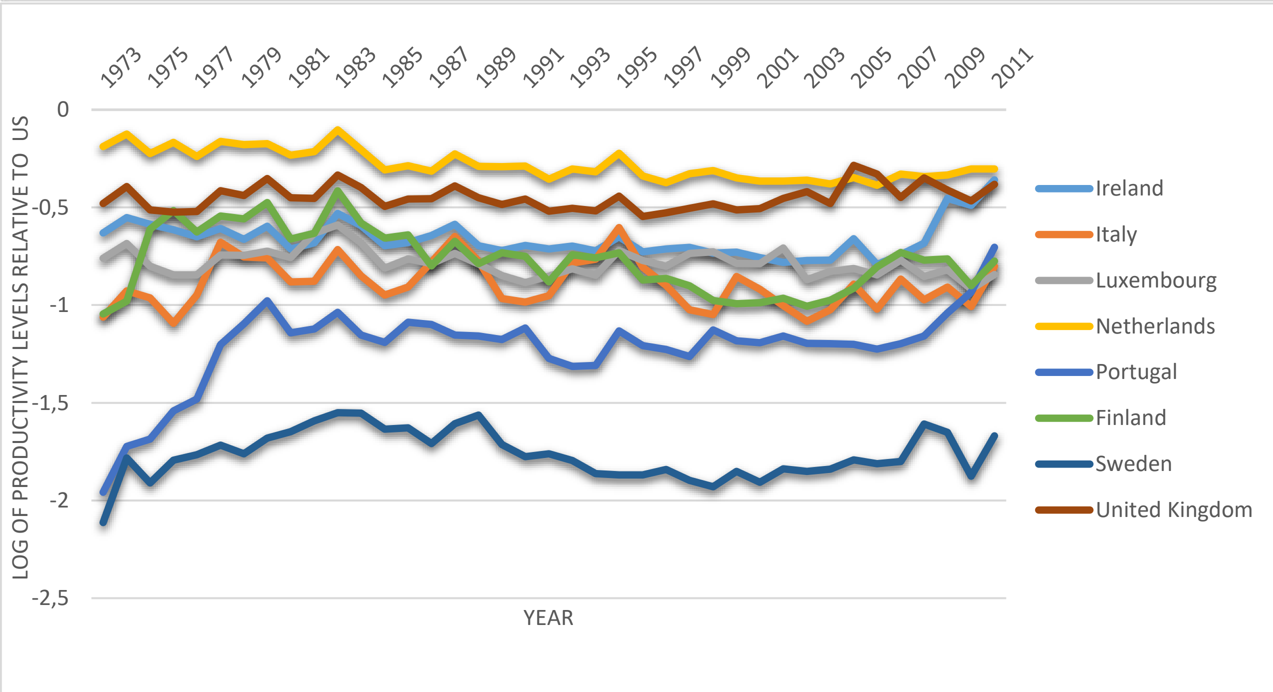
Figure 2 presents the trend of differences in relative levels of productivity of the fourteen European Union countries relative to the United States productivity (TFP_{US} =0)

Figure 2. Trends of differences in relative levels of productivity. EU countries (TFP_{US} =0)

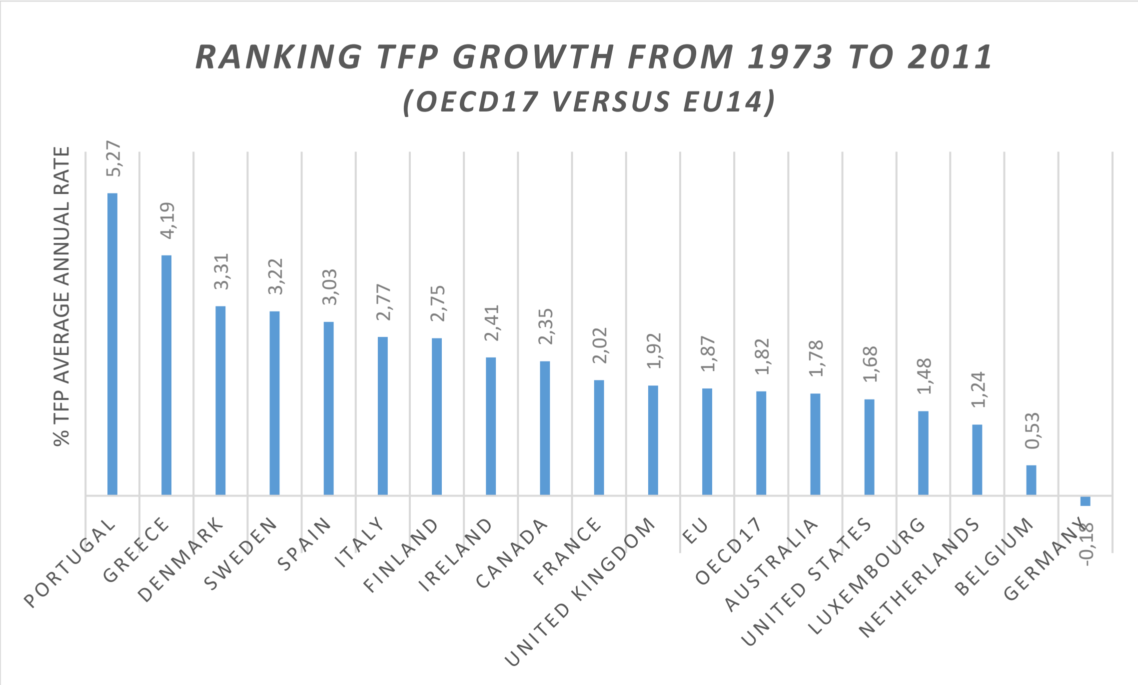




Source: Own elaboration

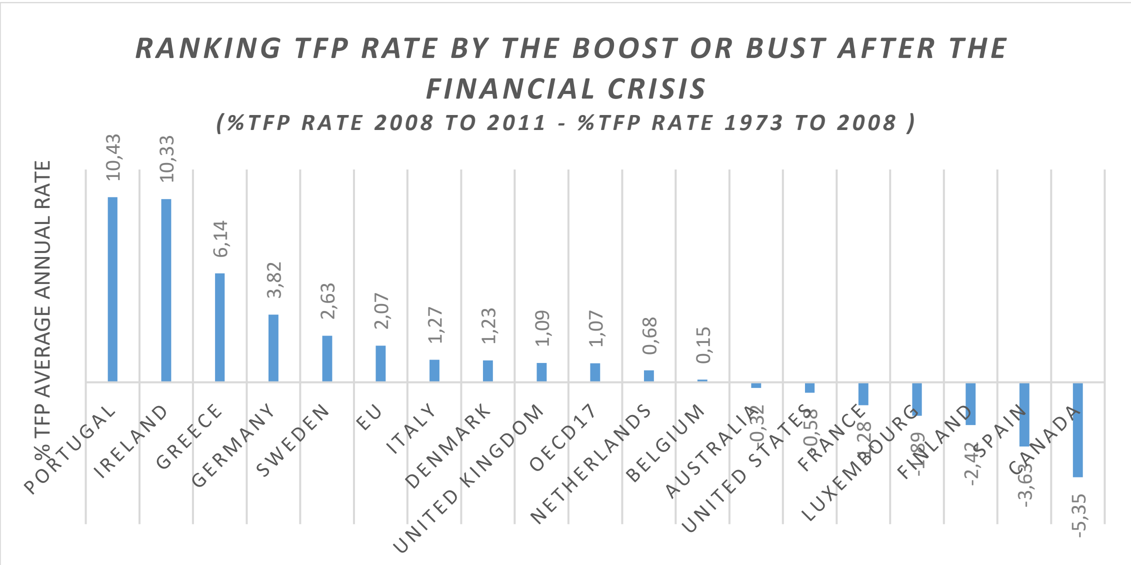
On average, the 17 OECD countries achieved a 1.82 per cent rate of TFP growth for the entire period, but below the EU average annual rate of growth of 1.87 per cent. The leaders, in the long run, were the Mediterranean and the Nordic countries. Canada's rate of growth exceeded the average, but not that of Australia, the United States and the Netherlands (Figure 3). Belgium had the lowest growth rate in productivity other than Germany, whose growth rate became negative after the reunification.

Figure 3 ***Ranking TFP growth from 1973 to 2011 (OECD17 versus EU14)***



Source: Own elaboration

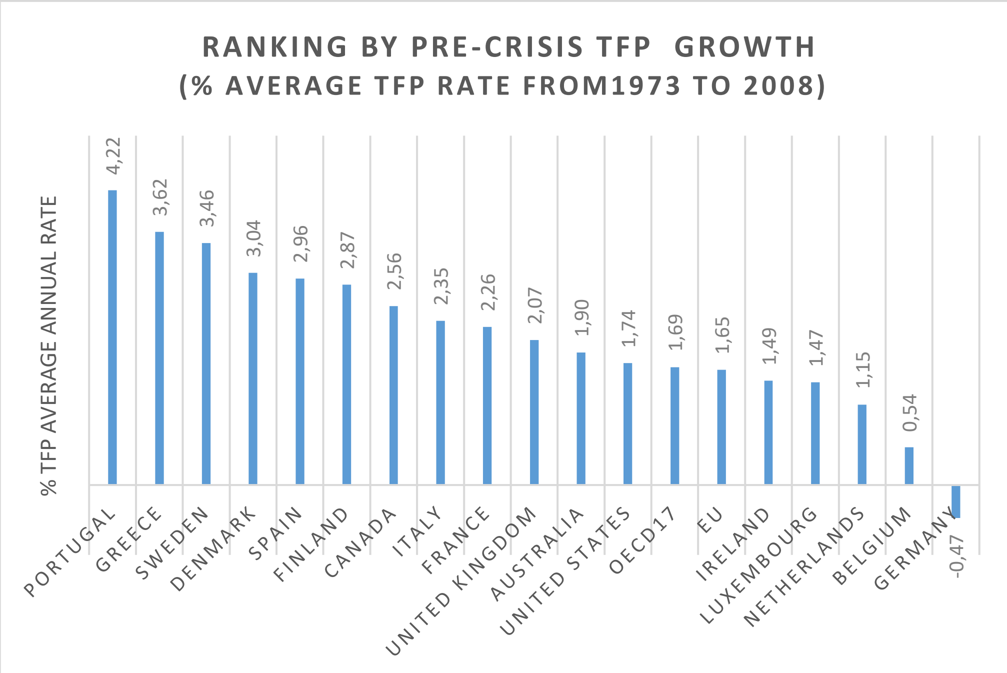
Figure 4 ***Ranking TFP rate by the boost or bust after the financial crisis. (%TFP rate 2008 to 2011 - %TFP rate 1973 to 2008)***



Source: Own elaboration

Figure 4 demonstrates the scope of the restructuring of the agricultural sector after 2008, comparing the historic productivity trend versus the post-crisis boost or bust. The positive bars on the left hand of Figure 4 indicate an acceleration of the rate of productivity growth following the financial crisis. The post-crisis growth rates in Portugal, Ireland, Greece, Germany and Sweden exceeded that for the years preceding the financial crisis. Italy, Denmark, and the United States achieved rates of productivity growth below the EU average in the post-crisis period, but above the average of the 17 OECD countries (Figure 4). Moreover, several countries experienced rates of TFP growth below the historical trend, namely Canada, Spain, Finland, France, the United States and Australia (Figure 4).

Figure 5 ***Ranking by pre-crisis TFP growth (% Average TFP rate from1973 to 2008)***



Source: Own elaboration

The differences in the post-crisis boost or bust (Figure 4) explain the changes in the ranking from the pre-crisis TFP growth (Figure 5) versus the total period (Figure 3).

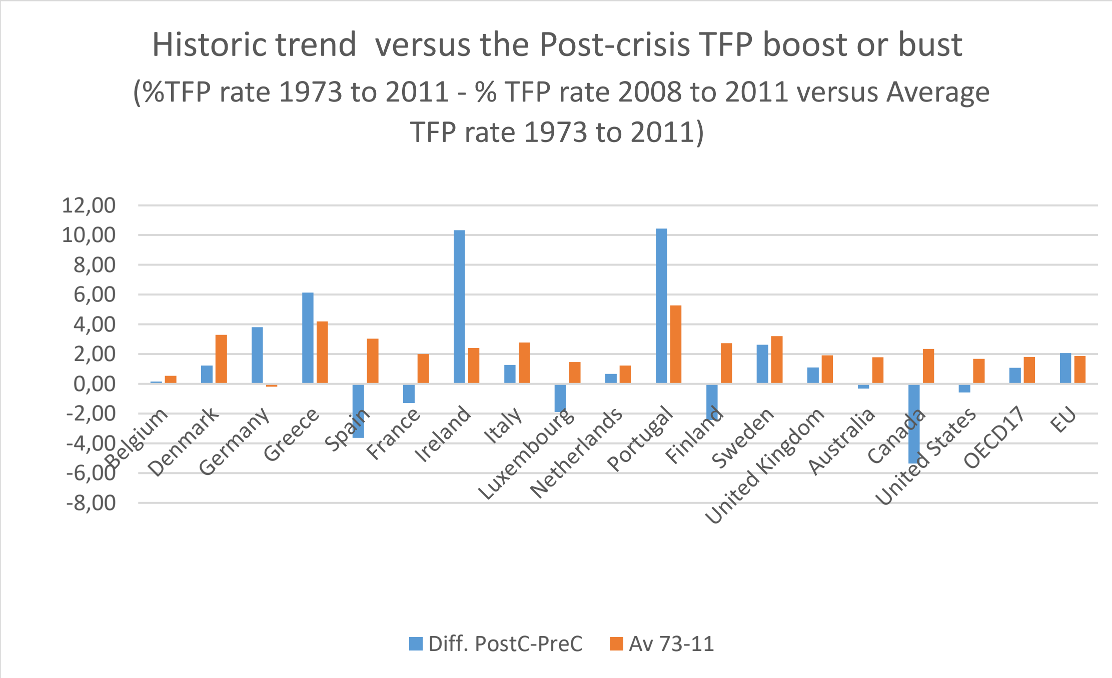
Notably, Australia and the United States fall below the average growth of the EU and the 17 OECD countries because of a slowdown in productivity growth after the financial crisis (Ball, Schimmelpfenig and Wang, 2013). Ireland exceeded the average in the ranking and Portugal achieved the highest rate of growth (Figures 3 and 5) due to the post-crisis boost in TFP growth. The Portuguese case is probably related to the fact that the agricultural land was nationalised after the "Carnation Revolution", and since 1975 the rent of agricultural land has been administratively fixed at low levels. Additionally, farmers had access to the European Structural and Investments Funds, which focuses on less developed regions of the EU, and also the CAP subsidies from 1986. From 1974 to 2011 the rate of growth of capital per unit of labor was 1.5 per cent for Portugal while Spain was only 0.6 per cent. The main difference was during the five years preceding the financial crisis, Portugal sharply increased the capital intensity whereas Spain saw a decrease. After the financial crisis both suffer a credit crunch and saw a reduction in capital input. This may explain the gains in productivity in Portugal relative to those in Spain during the post-crisis period (Figure I-4).

Figure 6 compares the historical trend in TFP growth (1973-2011) versus the Post-crisis boost or bust. Specifically, Figure 6 compares the average annual per cent TFP growth rate from 1973 to 2011, minus the per cent TFP growth rate 2008 to 2011 (orange bars) versus the average annual TFP growth rate from 1973 to 2011 (the blue bars).

This represents the post-crisis boost or bust. Among the 17 OECD countries, Canada, Spain, France, and Finland achieved negative differentials rates (bust) during the post-crisis period compared with the historical trend. However, Ireland, Portugal, Germany, Greece and Denmark show boosts, with an average annual rate of growth in TFP in 2008 to 2011 exceeding the historical trend growth rate (Figure 6). Australia and the United States show a smaller bust in productivity during the post-crisis period (Figures 6).

Figure 6 Historic trend versus the Post-crisis TFP boost or bust

(%TFP rate 1973 to 2011 - % TFP rate 2008 to 2011 versus Average TFP rate 1973 to 2011)



Source: Own elaboration

The ranking by country of the TFP average rate of growth during the post-crisis period shows that the EU average growth rate exceeds the growth rate of the 17 OECD countries. In the post-crisis period, countries with a high level of TFP (the United States and the Netherlands) achieved a rate of growth below the average of the 17 OECD countries. The consequences in the relative levels of productivity can be appreciated if we normalise the productivity level relative to the leader (TFP_{US} =1) in the Figures of Appendix I representing the per cent of the level of the leader, e.g. Australia 0.97 means that reach 97% of the US level in 1999 moreover after the century droughts fall to 0.69 or 69% of the US productivity level in 2003. The Netherlands shows the highest TFP level of the European Union countries, so is included in the figure I-1 to visualise the relative level of the EU countries versus Australia and Canada. See figures I-2 to I-4 for the evolution of the relative levels of the EU countries agriculture

In the period after the financial crisis of 2008, Portugal, Ireland, and Greece have the highest rates of growth in TFP. By contrast, Canada and Spain show negative TFP rates of growth in the post-crisis years, which explains their final fall in relative levels (Figure I-1 and I-4).

Having developed this unique panel dataset on agricultural TFP from 1973 to 2011, we examine if there is a process of convergence. The next section presents the empirical results of the model testing catching–up, embodiment, and the business cycle.

Empirical model results: catching–up, embodiment, and the business cycle.

First, we find evidence of catching–up among the seventeen OECD countries; second, we test the embodiment hypothesis; and third, we present the relation between convergence and the business cycle. More specifically, the rate of convergence is faster during years with a negative output-gap. Our model results are similar to those found for the US States. First, the estimate of β_1 (the coefficient on the initial level of TFP) is negative and statistically significant, indicating beta-convergence during the 1973 to

2011 period. There is robust catching-up in 17 OECD countries agriculture with different specifications because our empirical results with the different models for the 17 countries always show the estimate of β_1 is negative and statistically significant (Tables 1 to 4). We use the embodiment hypothesis to help explain why convergence patterns vary among the 14 EU countries and Australia, Canada, and the United States and within each group of countries that are observed to have different initial endowments and take different technology-adoption paths. Second, we test the embodiment hypothesis in OECD agriculture, and our results for the embodiment hypothesis differ depending on the period analysed (as in Ball et al. 2001). We also conclude that the capital-intensity plays different roles over the study period: positive and significant before 1981, not statistically significant from 1981 to 2008, and again positive and statistically significant after the financial crisis (see Table 1). The results show a decrease in the K/L coefficient driven by likely obsolescence of the capital stock, a result of higher fuel prices following the oil embargo, and negative net investment after 1981 (see Ball et al., 2001; 2016). After the financial crisis, the embodiment hypothesis holds unquestionably during the years of the negative output gap. Our results show that in the European Union countries, the coefficient on capital intensity is 0.092 (Table 2 column 2) against 0.320 for the 17 OECD countries (Table 1 column 3). In Table 3 column 3 using Generalised Method of Moments (GMM), our result (0.275 for the K/L ratio for years with negative output-gap) is similar to Table 1 using fixed-effects estimates, with the coefficient on the K/L ratio of 0.320 (Table 1 column 3). After the financial crisis, the coefficient on the K/L ratio becomes positive and significant. Therefore, we conclude that the capital-intensity matters for the convergence during the years of negative output-gap.

Table 1 summarises the model results with panel data and fixed effects (within regression). The dependent variable is the TFP rate of growth, while the independent variable is the initial level of TFP. The control variables include first K/L or capital intensity to assess the embodiment hypothesis. We also include as control variables the Output-gap with two lags and TFP with one lag [Og(-2)*TFP(-1)] to control for the memory of the process; the D_kl Dummy 1981 is the cross elasticity with the capital intensity per worker, to reflect the observed change in the trend of capitalisation per unit of labour working in agriculture[9]. The National total factor productivity of the economy (nTFP), is included to capture the technology spillovers. Finally, Hc the Human capital index, intended to capture specific characteristics of the labour force of each country and spillovers from the improvements in education.

[9] The difference with the 1981 dummy in Ball et al. 2016 is that here D_kl is a cross-elasticity and the interpretation of the signs is on the opposite way. The D_kl cross-elasticity negatie sign meaning the K/L ratio is positivily related with convergence.The interpretation of the results holds.

Table 1 Fixed effects (within regression) OECD

Dependent variable: TFP Growth	(1) All observations	(2) Observations with a negative output-gap	(3) Observations as of 2008: post-big recession	(4) All observations. Output-gap 2 lags by TFP one lag: Og(-2)*TFP(-1)
TFP(-1)	**-0.160****	**-0.267*****	-0.595**	**-0.159****
	(0.06)	(0.06)	(0.25)	(0.06)
Og(-2)*TFP(-1)				**0.020****
				(0.00)
Capital/labour	0.028	0.051	**0.320*****	0.031
	(0.03)	(0.03)	(0.07)	(0.03)
Capital/land	0.021	**0.066****	-0.037	0.023
	(0.01)	(0.03)	(0.02)	(0.02)
Time effects	Yes	Yes	Yes	Yes
Fixed effects (countries)	Yes	Yes	Yes	Yes
Cross-sections included	17	17	17	17
Total panel observations	646	317	68	646

Source: Own

The main remarks from Table 1 are the following. First, the speed of convergence in levels of TFP increases with negative output-gap. Second, the more negative the output-gap, the faster the convergence in TFP (column 4). Third, the intensity of capital by land is only significant when the output-gap is negative (column 2). We find that only during recessions (or negative output-gap) does K/A explain the differences in convergence rates between OECD countries. The level of TFP for the aggregate economy (nTFP) is significant, especially during years with a negative output-gap, so we identify relevant spillovers from the aggregate economy to growth in agricultural productivity. An interpretation of the model results is that the economies with high TFP levels generate spillovers that accelerate convergence in levels of TFP during the downturns. Our model's results clearly demonstrate that the speed of convergence in the EU is more rapid during years with negative output-gap. Conversely, the EU countries rate of catch-up during the periods performing below the full capacity of the economy is slower than the rest of the 17 OECD countries (see Tables 1 and 2). Next, to determine if the Common Agricultural Policy, the European Structural and Investment Funds (ESIF) and other European policies and characteristics affect the convergence process, the same model as in Table 1 is estimated in Table 2. The difference is that in Table 2, the sample includes only the EU Member States.

Table 2 Fixed effects (within regression). Only the EU Member States

Dependent variable: TFP Growth	Column 1 All EU MS	Column 2 Only EU MS with negative output-gap	Column 2 Members of the EU (post-great recession)
TFP(-1)	**-0.140****	**-0.199***	**-0.552****
	(0.04)	(0.09)	(0.23)
Capital/labour	0.057	**0.092***	0.305
	(0.03)	(0.04)	(0.18)
Capital/land	0.003	**0.030****	-0.035
	(0.01)	(0.01)	(0.04)
Time effects	Yes	Yes	Yes
Fixed effects (countries)	Yes	Yes	Yes
Cross-sections included	14	14	14
Total panel observations	460	217	56

Source: Own

The model results in Table 2 allow us to examine if the rate of convergence for the EU countries is slower than when we consider all the countries in the sample.

Results suggest that European policies (CAP and ESIF) act as a safety net for less productive farms, possibly delaying bankruptcies and exiting of the industry.

The fixed effects results (within regression) for the EU Member States suggest that during periods of negative output gaps, the convergence process in Europe is faster, and the importance of capital intensity is more significant.

Besides, when output gaps are negative, the relevance of capital intensity is higher in Europe. The level of productivity of the economy, nTFP, seems to be relevant for the TFP convergence during the negative output-gap years in the EU.

Table 3. Generalised method of moments (GMM). OECD 17 countries 1973-2011

Dependent variable: TFP Growth	**Column 1** **All years**	**Column 2** **Negative output-gap years only**
TFP(-1)	**-0.371****	**-0.515****
	(0.17)	(0.13)
Capital/labour	**0.206***	**0.275****
	(0.11)	(0.11)
Capital/land	0.003	0.072
	(0.11)	(0.05)
Time effects	Yes	Yes
Fixed effects (countries)	Yes	Yes
Cross-sections included	17	17
Total panel observations	646	317

Source: Own

Notes:

a) Column 1: All observations: endogenous variable instrumented with lags: TFP (-1)
b) Column 2: Observations with negative output gap: endogenous variable instrumented with lags: TFP (-1)

However, estimations in Table 1 and Table 2 may be biased due to the endogeneity of the regressors. Hence, we re-estimate the model but using a two-step difference GMM estimator (Arellano and Bond, 1991). All variables are considered endogenous, and the standard errors are finite-sample corrected (Windmeijer, 2005). Moreover, and in order to keep the properties of the Hansen test (Roodman, 2009) and avoid problems of overfitting instrumented variables (Bowsher, 2002), the number of lags is limited to four.

Note that the two-step system GMM proposed by Blundell and Bond (1998) is discarded since the panel is balanced, $\beta1$ is far from being a unit root ($\beta1$ -> 1), and the GMM estimates obtained lie above the Within Groups estimates (for more details of this rule of thumb, see Bond et al., 2001). Hence, little or no gains in efficiency can be obtained from using a system GMM estimator, with the added problem of introducing more instruments.

Now with the GMM estimations (Table 3), we use values in lags of the same endogenous variables as instruments. This way, we can eliminate endogeneity arising from autocorrelation. The coefficients vary considerably across the regressions, but, in essence, they continue showing the same conclusions, namely that there is convergence and the rate of convergence increases during periods of a negative output gap. In addition, the K/L ratio is always significant and has a greater impact during years with a negative output gap. The embodiment hypothesis holds.

For the remaining regressors, all the coefficients have the expected sign and are significant. Human capital stands out as the primary driver in convergence in TFP. Regarding the catching-up process, the convergence is not symmetric, and as in Ball et al. (2014), we found results confirming that countries below the average levels of TFP converge at a considerably faster rate than those above the average.

Conclusions

First, we find evidence of convergence in TFP levels across the different phases of the business cycle. However, the speed of convergence was much higher during periods of contraction in economic activity (negative output gap) than during periods of expansion (as in Ball et al., 2001 and 2014).

Model results clearly demonstrate that the speed of convergence in the EU is more rapid during years with negative output-gap. Conversely, the speed of convergence among the EU countries during the economic slowdown is slower than in Australia, Canada and the United States (see Tables 1 and 2).

Our findings are consistent with those from the manufacturing sector. In contrast with manufacturing, however, the magnitude of the effects of the business cycle appears to be smaller in the agricultural sector. We attribute this to public funding of R&D in the agricultural sector.

Regarding the EU versus Australia, Canada and the United States, our model results show that the European Union TFP is catching up in the long run.

The results of testing the embodiment effect on TFP growth are positive (Table 3). Therefore, we conclude that the embodiment effect is essential during the years of negative output-gap but is not significant during years with a positive output-gap.

Finally, we found significant spillovers from investment in human capital leading to more rapid productivity growth. The level of productivity of the national economy also contributes positively to the growth of agricultural TFP during downturns. Finally, there is evidence that countries with below average TFP levels converge to the mean level at a faster rate than nations with high average TFP levels.

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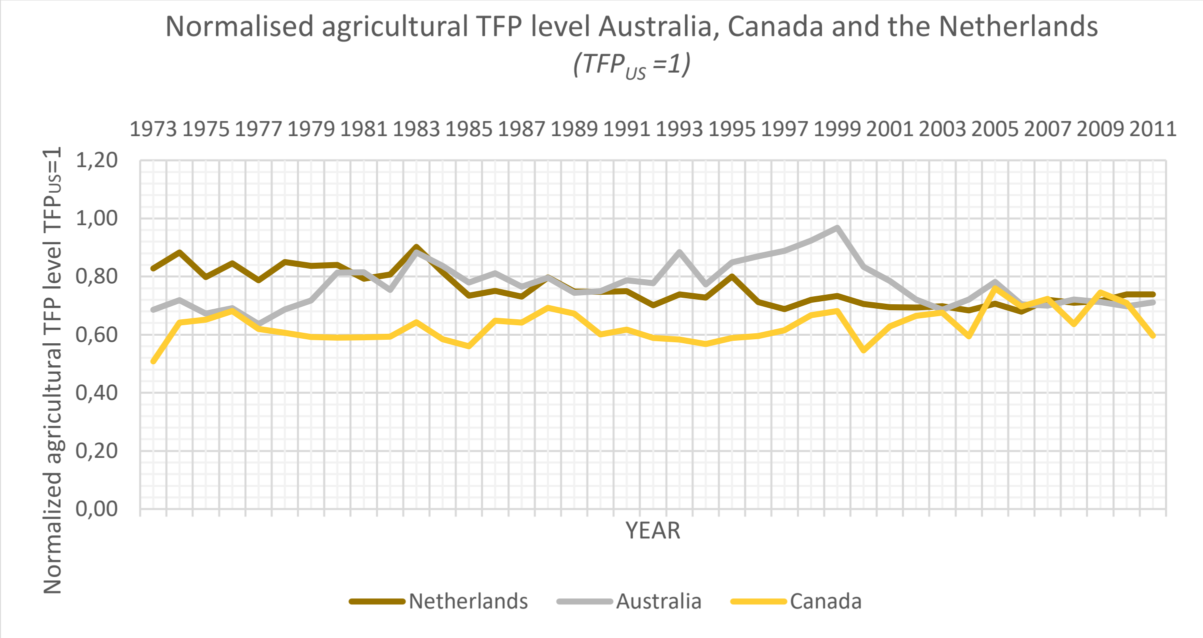
Appendix I

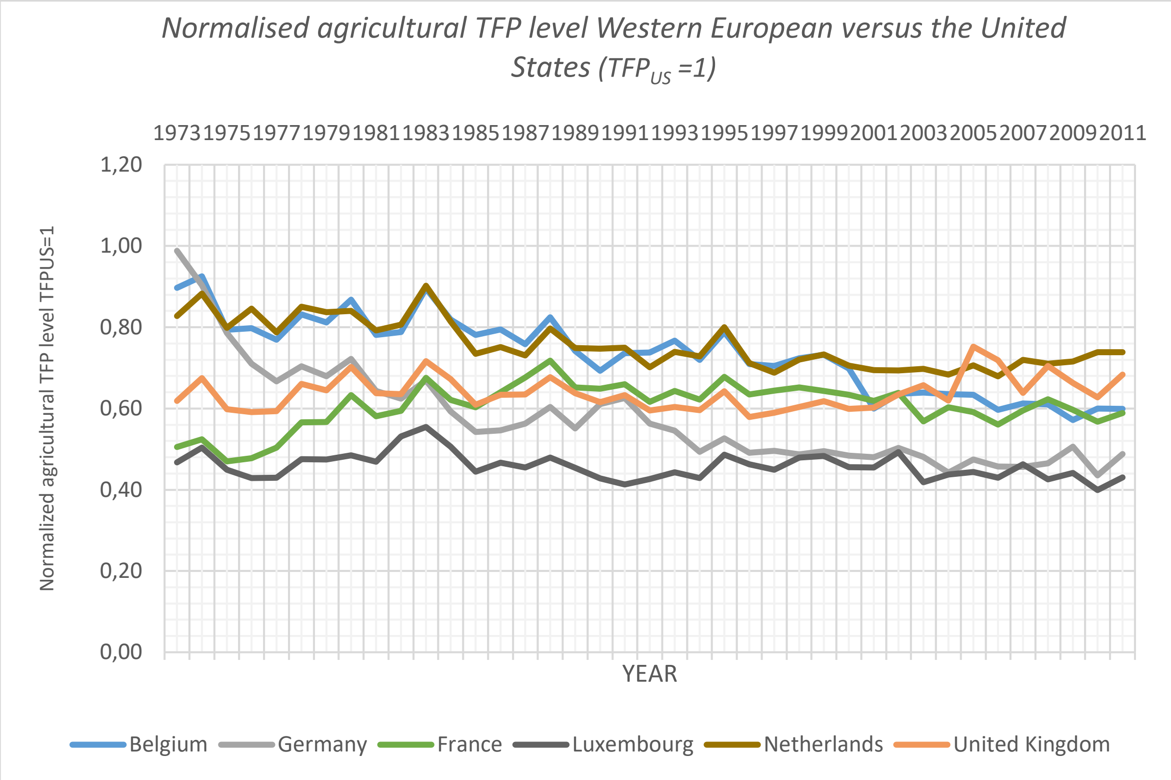
Figure I 1 Normalised agricultural TFP level Australia, Canada and the Netherlands[10]



Source: Own elaboration

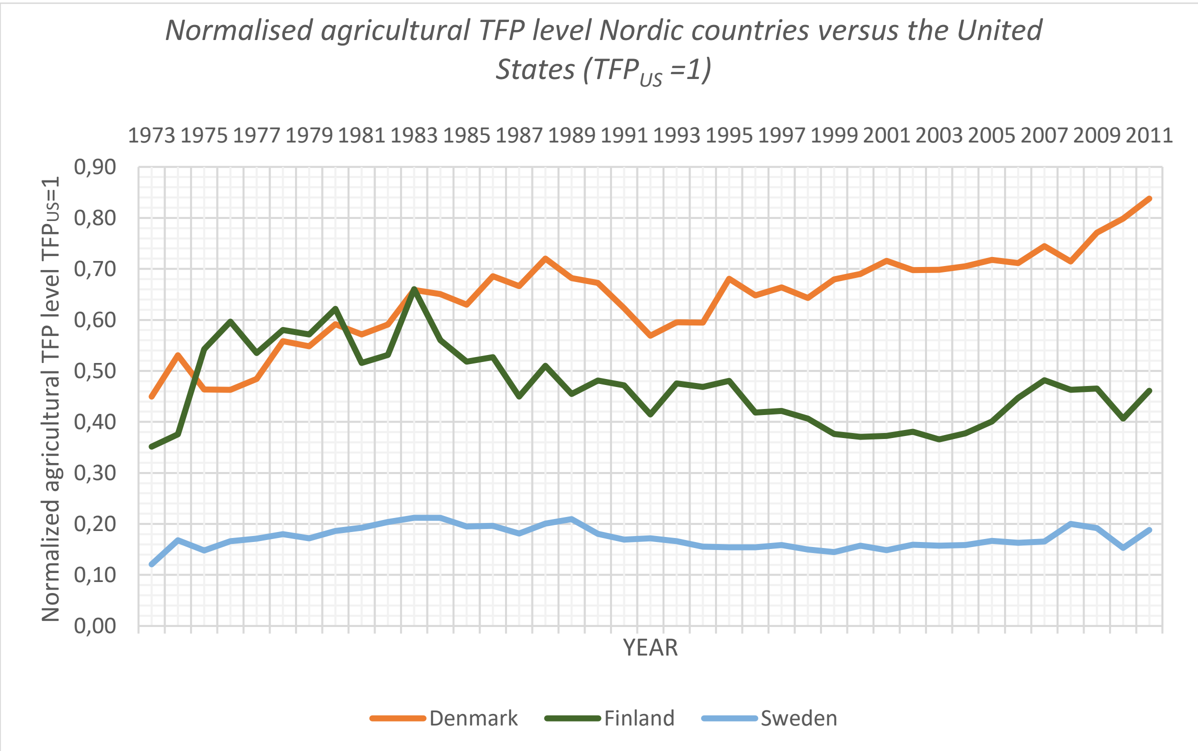
[10] The US present the highest productivity level every year so we normalize TFP_{US} =1 and the countries figures represent the per cent of the level of the leader, e.g. Australia 0.97 means that reach 97% of the US level in 1999 moreover after the century droughts fall to 0.69 or 69% of the US productivity level in 2003. The Netherlands shows the highest TFP level of the European Union countries, so is included in the figure I-1 to visualise the relative level of the EU countries versus Australia and Canada. See figures I-2 to I-4 for the evolution of the relative levels of the EU countries agriculture.

Figure I 2 Normalised agricultural TFP level Western EU countries (TFP_{US} =1)



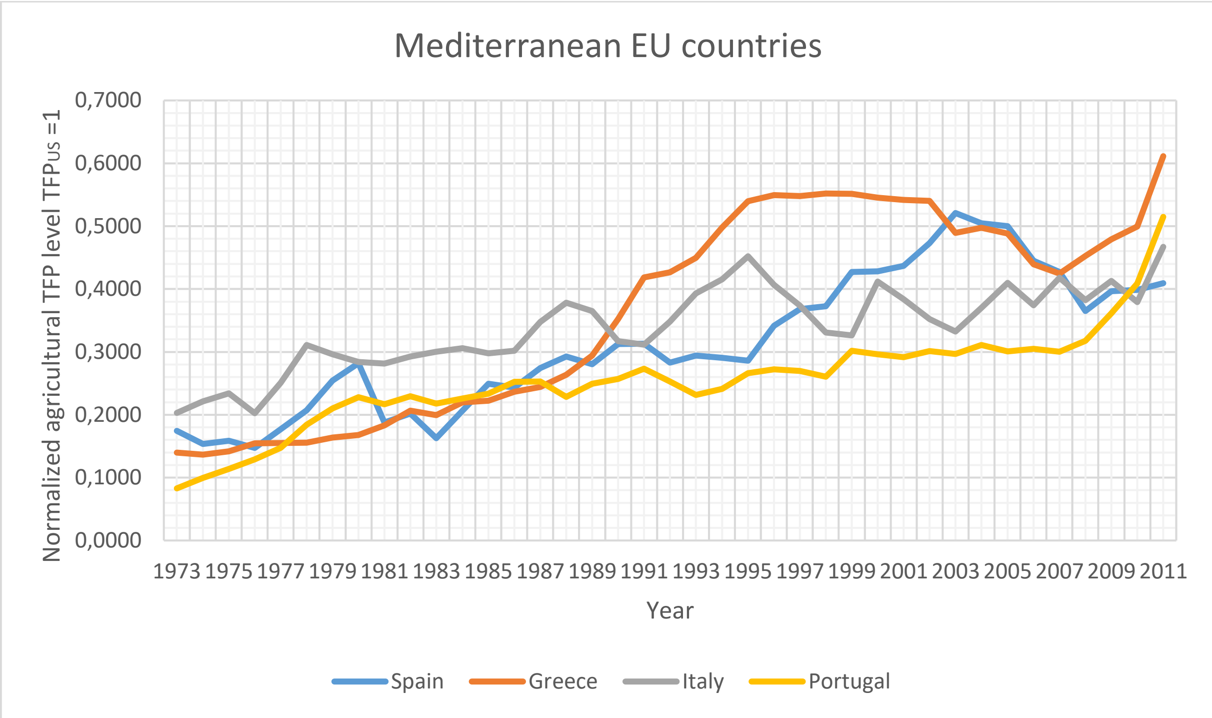
Source: Own elaboration

Figure I 3 Normalised agricultural TFP level Nordic Countries TFP (TFP_{US} =1)



Source: Own elaboration

Figure I 4 Normalised agricultural TFP level Mediterranean EU Countries



Source: Own elaboration