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Abstract

This article presents a model of macroeconomic growth that combines in a single formalization two complementary views on innovation and economic growth, the technology-gap approach and the Kaldorian theory of cumulative causation. The model suggests that what matters for economic growth in the long run is the existence of a good match between the patterns of technological change, income distribution and demand growth. The model is estimated for the Spanish economy during the period 1960-2001, and the econometric results show that important changes have happened in its growth regime over time. Since the 1980s, innovation and diffusion of new technologies provide with a greater stimulus to productivity growth, but the technology push on the supply-side is not sustained by the prevailing patterns of income distribution and demand growth.

Key words: Innovation, diffusion, cumulative causation, economic growth

JEL Classification: O11, O30, O40.

1. Introduction

There has been a great surge of interest in growth theory in the last two decades. The way in which the neoclassical theory of growth (Solow, 1956) dealt with technical change as an exogenous residual has been increasingly criticized, and extensive research has been done to explain its fundamental role. On the one hand, 'new growth theorists' have inserted technological change into an equilibrium framework, and built up models of innovation-driven endogenous growth (Romer, 1986 and 1990; Lucas, 1988; Aghion & Howitt, 1992).

On the other hand, a large group of heterodox scholars, mainly inspired by classical authors such as Marx, Schumpeter, Keynes and Kaldor, have focused on the disequilibrium features of the process of technological and economic change. Neo-Schumpeterian, evolutionary and post-Keynesian theorists have all pointed out that economic growth is not a simple transition towards the steady state, but rather a complex process of evolution, transformation and qualitative change. In such a complex process, a prominent role is played by the dynamic relationships between technological, economic and institutional changes.

However, behind this broad agreement on the disequilibrium features of the process of economic growth, important differences exist among these heterodox theories of growth. Neo-Schumpeterian and evolutionary theories (following the seminal contributions by Freeman et al., 1982; and Nelson & Winter, 1982) have so far focused on the determinants and impacts of technical change on the supply side of the economy. Post-Keynesian approaches (Dixon & Thirlwall, 1975; Boyer, 1988), on the other hand, have taken the demand side into greater account.

Rooted in this broad 'disequilibrium' tradition, the present paper argues that the role of technological change for macroeconomic growth can be more fruitfully analysed by considering both aspects in the same framework, supply and demand. The technology-push on the supply side is fundamental in the modern knowledge-based economy, but demand still provides with important incentives, opportunities and constraints that have often been neglected by recent research (Castellacci et al., 2005).

With the purpose of combining supply and demand-side aspects into the same framework, section 2 presents two complementary theories of technical change and macroeconomic growth: the ‘technology-gap approach’ (Fagerberg, 1987 and 1994), which gives a prominent role to the national creation of innovation and the international diffusion of new technologies, and the ‘Kaldorian model of cumulative causation’ in the version developed by Boyer (1988), which points to the importance of the dynamics of aggregate demand and income distribution.

The model presented in section 3 and 4 combines these two complementary views in a single formalization, building on previous works along similar lines by Verspagen (1993), Amable (1993), Targetti & Foti (1997), Ledesma (2002) and Castellacci (2002). In order to refine these previous formalizations, the model presented here adds the internal components of aggregate demand (consumption and investment) to the analysis of the cumulative causation mechanism, and it thus explores the important relationships between income distribution, demand dynamics, technical change and economic growth.

Section 5 presents the results of an econometric analysis of the model for the case of Spain (1960-2001), and it devotes particular attention to study the important changes that have happened in the working of the model in these four decades. Section 6 concludes the paper with some final remarks.

2. Two complementary theories of technological change and macroeconomic growth

Recent growth theorizing has mainly focused on the creation and diffusion of new technologies on the supply side of the economy, and the role of demand has often been neglected (Castellacci et al., 2005). Some research traditions, however, have pointed out the fundamental role of demand in creating incentives, opportunities and constraints to technological and economic development. In particular, the relationships between institutions, technology and the demand side of the economy have been extensively analysed by the French school of *régulation* (Boyer, 1988 and 2003; Boyer & Petit, 1988 and 1989).

This approach studies economic and technological issues within a broad range of social and institutional relationships, providing with a dynamic view able to combine the study of economic and technological changes within a given historical path. The Regulation theory conceives the economic system as ‘regulated’ by a complex set of economic, technological, social and institutional factors. Only a good match between these factors may lead to sustained growth in the long run, while a mismatch can lead to the crisis of the system and possibly to the modification of the *modes de règulation*. The latter is defined by a large set of institutional forms and technological opportunities, which establish the conditions required to ensure stable and sustained economic growth.

In the *régulation* theory, the description of the process of economic growth is greatly inspired by the Kaldorian cumulative causation model. Built on the original ideas of Myrdal (1957) and Kaldor (1957 and 1981), further developed by Dixon & Thirlwall (1975) and reinterpreted along Regulationist lines by Boyer (1988), the Kaldorian cumulative growth model is based on a process of interaction between growth of demand and growth of productivity. This dynamic interaction is developed through two interrelated mechanisms. On the one hand, the existence of Kaldor-Verdoorn returns to scale is assumed to link aggregate demand to productivity growth (so-called ‘productivity regime’). The source of this relationship can be different: static increasing returns to scale, the deepening of the division of labour due to the expansion of the market, technological changes embodied into machineries and equipments, learning by doing and learning by using mechanisms (Vivarelli, 1995).

On the other hand, the ‘demand regime’, that is the relationship from productivity to demand growth, is based on two mechanisms, an external and an internal one (Pini, 1996). The external causation mechanism depends on the dynamics of the foreign component of aggregate demand, exports. These may be influenced by the dynamics of foreign markets, by costs and non-costs competitiveness of foreign goods, by the dynamics of the exchange rate, and by the one of labour productivity. The latter, in particular, affects the terms of trade and thus the competitiveness of national products on foreign markets.

The internal causation mechanism is based on the dynamics of the internal components of aggregate demand, private consumption and investments, and on the way in which these may be stimulated by the productivity increases, and by the related patterns of distribution between profit earners and wage receivers. In fact, private firms distribute the benefits of technical progress to both, capitalists and employees, and the distribution patterns affect in turn the growth path of investments, consumption and aggregate demand.

On the whole, the Kaldorian cumulative growth model (in the formulation put forward by Boyer, 1988), points out that the main source of economic change is the dynamic interaction between the productivity regime and the demand regime (driven by the internal and external causation mechanisms), thus giving a fundamental role to the demand side of the economy.

Neo-Schumpeterian and evolutionary scholars (Freeman et al., 1982; Nelson & Winter, 1982), however, have shown that productivity growth is not simply a demand-led story, and the technology-push on the supply side is also a fundamental engine of growth. In the past few decades, many middle-income countries have been able to catch-up by imitating, using and improving the new technologies developed in more advanced countries (Fagerberg, 1987 and 1994; Fagerberg & Godinho, 2004). The creation of innovation, together with the diffusion of knowledge and advanced technologies from abroad, constitute therefore an important and complementary source of growth that needs to be taken into account.

Building on the seminal contributions of Gerschenkron (1962), Cornwall (1977) and Abramovitz (1986 and 1994), technology-gap studies of economic growth have shown that the domestic capability to absorb knowledge spillovers from abroad is a key factor in order to explain growth rate differentials between countries. According to the technology-gap theory (Fagerberg, 1987 and 1994; Verspagen, 1993), the succesful adoption and use of new technologies is "a costly activity, that requires investment in indigeneous capabilities, capital equipment, infrastructure, etc. Without a sufficient level of such investments, a country is unlikely to benefit from backwardness, and risk of falling behind relative to the technology leaders, rather than 'catching up'" (Verspagen, 1991). Thus, following this perspective, economic growth may be seen as the outcome of three sets of factors (Cappelen et al., 2003).

First, the new technologies developed in the country by its internal innovative activity. Second, the potential for exploiting more advanced technologies developed elsewhere (i.e. the international diffusion of technologies). Such potential depends on the technological backwardness of the country, but it is also affected by its 'technological congruence' and 'social capability' (Abramovitz, 1986), without which this process of technology diffusion may be hampered. Third, a set of social and institutional factors affects the extent to which this potential is realized. Among these factors, Abramovitz (1994, p.26) points out "the facilities that laggard countries have for learning about more advanced methods, for appraising them and for acquiring them"; "the determinants of resource mobility", because they facilitate the process of structural change required by the aggregate productivity growth; and the "macroeconomic conditions that govern the intensity of use of resources and the volume of investment activity", which influence "the rate at which more advanced technology is incorporated into production". The applied works in the technology-gap tradition, recently surveyed by Fagerberg & Godinho (2004), confirm the hypothesis that national innovation and international diffusion of technologies are indeed fundamental factors to explain differences in national patterns of economic growth in the long run.

3. Innovation, diffusion and cumulative causation: structural form of the model

The cumulative causation mechanism generated by the interactions between growth of productivity and demand, together with the creation of innovation and the international diffusion of technology may be conceived as strictly interrelated and complementary sources of macroeconomic growth. The growth model presented in this section takes into account both, demand and supply sources of economic growth.

The main idea of the model is presented in Fig.1. Besides creating new technologies through its national system of innovation, a country lagging behind the technological frontier may also benefit from the process of catching up through the diffusion of innovation created elsewhere, if it counts with the basic structural characteristics to exploit this potential.[1] This may lead to the introduction of new technologies and thus, to rapid increases of productivity. The technology-led productivity growth, however, may also stimulate the different components of aggregate demand. In fact, an increase in productivity can either raise the competitiveness by decreasing prices (therefore stimulating exports), or it can be redistributed to both, wage receivers and profit earners (thus pushing private consumption and investments). In turn, the growth of aggregate demand can spur further increases in productivity through Kaldor-Verdoorn returns to scale, thus possibly activating a cumulative causation virtuous circle.

On the whole, as it is shown in Fig.1, the main engines of growth are assumed to be both, the innovative activity of a country internally developed, and the imitation of advanced foreign technologies. The specific hypothesis put forward here is that, in order for this mechanism to lead to stable and sustained growth in the long run, the way in which the productivity increases are distributed among wage receivers and profit earners matters significantly. In other words, the rapid growth and catching up process may not be realised either if a country lacks the capability to exploit the potential for diffusion (as pointed out in the technology-gap literature), or if the interactions between distribution and aggregate demand components lead to a vicious rather than a virtuous pattern of economic growth (as it is possible in the Regulationist-Kaldorian framework).

< Figure 1 here >

This is our theoretical starting point, on which the analysis presented in the remaining of the paper is based. Five macroeconomic growth models have previously explored a similar idea. In Verspagen's model (1993, ch.5 and 6), the technology-gap growth is formalized through non-linear knowledge spillovers that flow towards the backward country. These spillovers determine the dynamics of the technology-gap and the final result in terms of productivity growth rates. The outcomes of this model are mainly determined by the dynamics of the technology-gap, while the role played by the cumulative causation mechanism is not central. In Amable's linear model (1993), the cumulative causation mechanism is represented through the interactions between endogenous investments, innovative activity and human capital. The econometric model by Targetti & Foti (1997) is mainly based on the relationships between productivity, demand and exports. Ledesma's model (2002) refines the cumulative causation mechanism presented by Amable by including the exports. Finally, combining the Verspagen with the Regulation model, Castellacci (2002) has inserted the productivity-demand interactions into a non-linear framework.

Building on these previous works, the present model adds the internal components of aggregate demand (consumption and investments) to the cumulative causation mechanism, in order to explore the important relationships between income distribution, demand dynamics, technical change and economic growth. The 8 linear equations of the structural form of the model are presented in the remaining of this section. Since the analysis focuses on the dynamic relationships between variables over time, all the variables in each equation are defined as annual rates of change (Vivarelli, 1995; Pini, 1996).

$$AP = a_0 + a_1GI + a_2X + a_3INNO + a_4GAP + a_5STRUCT \tag{1}$$

This equation for the determinants of the growth of average productivity (AP) is the very core of the model, representing the dynamics of the supply side. The first two explanatory variables are typical of the Regulationist-Kaldorian view (Boyer, 1988), according to which increases in productivity can be obtained either through technical progress embodied in new capital equipments via gross investments (GI); or through increases in aggregate demand (X), which can generate dynamic economies of scale and learning by doing (the Kaldor-Verdoorn effect). On the other hand, we also assume that a large part of productivity growth may be explained by the technology-gap hypothesis (Fagerberg, 1987). According to this, the growth of productivity depends on the national innovative activity that generate new products and new processes (INNO); on the potential for the exploitation of foreign technologies (measured by the variable GAP, indicating the dynamics of the technology-gap between the country and the technological leader); and on the structural factors affecting to what extent this potential is realised (STRUCT).

$$X = b_0 + b_1C + b_2GI + b_3EXP \tag{2}$$

According to a Keynesian view of ‘demand-led’ production, the overall increase over time in demand (X) depends on the sum of the dynamic patterns of its components, that is private consumption (C), gross investments (GI) and exports (EXP).

$$C = c_0 + c_1RW + c_2PROF \qquad (3)$$

The dynamics of private consumption (C) depends on the growth of the purchasing power of the wage earners (i.e. the growth of their real wage RW), and on that part of profit of firms (PROF) that is redistributed to and consumed by profit earners.

$$GI = d_0 + d_1PROF + d_2X \qquad (4)$$

Gross investments (GI) depend first on that part of the extra-profit (PROF) obtained by firms that are not redistributed but reinvested, according to a ‘classical’ view of investments; and, second, they may also depend on aggregate demand (X), according to a typical ‘Keynesian’ accelerator mechanism (Boyer & Petit, 1989; Vivarelli, 1995; Simonetti et al., 2000).

$$EXP = e_0 + e_1AP + e_2EER + e_3INNO + e_4OPEN \qquad (5)$$

Equation 5 defines the rate of change of exports (EXP). First, this is assumed to depend on the real rate of exchange (EER), an important factor defining the price competitiveness of the country. Second, export growth is positively linked to changes in the degree of openness of the economy (OPEN).[2] Third, it depends on other factors affecting the non-price competitiveness, such as the innovative activity internally developed (INNO), and the dynamic patterns of the average productivity (AP), both measuring the technological and quality improvements of national products competing in international markets (Fagerberg, 1988; Ledesma, 2002).

$$PROF = f_0 + f_1AP + f_2INNO \qquad (6)$$

The extra-profits of firms (PROF) are mainly obtained through productivity gains (AP). They may also be directly related to the innovative activity of the firms (INNO), as a higher rate of innovation may lead to higher extra-profits.

$$RW = g_0 + g_1AP + g_2U \qquad (7)$$

The dynamics of real wages (RW) is postulated to be affected first, by the distribution to workers of the productivity gains (AP); and second, by a possible labour market effect, according to which real wages may decrease when the rate of unemployment (U) grows (Vivarelli, 1995). Thus, the coefficients g_1 and g_2 represent in a stylised way the wage formation mechanism, which greatly depends on the institutional set up and the historical conditions that characterize the labour market (Boyer, 1988).

$$P = h_0 + h_1AP + h_2INNO \qquad (8)$$

Equation 8 assumes that the dynamics of prices (P) is affected by: (i) the increases of the average productivity (AP), that may be partly translated into lower prices in a context of high market competition; (ii) the dynamics of the innovative activity (INNO), which may determine further decreases in prices through the introduction of new products and processes in a highly competitive market.

On the whole, the model is an attempt to combine technological trends on the supply side with income distribution patterns on the demand side. The model considers both, the creation and the diffusion of new technologies, and the dynamic interrelationships between demand and productivity. In particular, equation 1 combines the technology-gap hypothesis with a Kaldorian ‘productivity regime’; equations 6 to 8 define the distribution of the increases in productivity between profit earners and wage receivers; and equations 3 to 5 define the impacts of the distribution patterns on the various components of demand, which, in turn, are expected to determine further improvements in productivity, thus leading to cumulative growth.

4. Sub-reduced forms and analytical properties of the model

This section focuses on the sub-reduced forms and the analytical properties of the model, the purpose being to analyse the effects of the inclusion of the technology-gap variables in the Regulationist-Kaldorian framework.[3] First of all, by solving the structural form we obtain the sub-reduced forms of the model for the productivity and the demand respectively. By using equations 1, 4, 6 and 8, we derive the ‘productivity regime’ (PR), which is the linear relationship that links demand to productivity growth:

$$AP = \alpha + \beta X \qquad (9)$$

where:

$\alpha = (a_0 + a_1d_0 + a_1d_2f_0 + a_3INNO + a_4GAP + a_5STRUCT) / (1-a_1d_2f_1)$,

and:

$\beta = (a_1d_1 + a_2) / (1\text{-}a_1d_2f_1)$.

The other sub-reduced form is the 'demand regime' (DR), which is the linear relationship that links productivity to demand growth. It is obtained from equations 2, 3, 4, 5, 6, 7 and 8:

$$X = \gamma + \delta AP \qquad (10)$$

where:

$\gamma = (b_0 + b_1c_0 + b_2d_0 + b_3e_0 + b_1c_1g_0 + b_1c_1g_2U + b_1c_2f_0 + b_2d_2f_0 + b_3e_3OPEN + b_3e_2EER) / (1\text{-}b_2d_1)$,

and:

$\delta = [b_1c_1g_1 + f_1(b_1c_2 + b_2d_2) + b_3e_1] / (1\text{-}b_2d_1)$.

Considering first the productivity regime, its y-intercept depends on the coefficients that represent the technological characteristics of the system (a_0, a_1), those entailing the idea of technology-gap (a_3, a_4, a_5), and those that define the type of investment (d_0, d_2, f_0, f_1). Its slope, on the other hand, depends on the coefficients representing the technological characteristics of the system and the type of investments (a_1, a_2, d_1, d_2, f_1). Turning to the demand regime, both its y-intercept and its slope depend on the coefficients that define the type of investments and the characteristics of the distribution of the average productivity increases (b_0, b_1, b_2, b_3, c_0, c_1, c_2, d_0, d_1, d_2, e_0, e_2, e_3, f_0, g_0, g_2).

Then, compared to the original formulation by Boyer (1988), a first analytical property of the model is outlined as follows. The inclusion of innovation and diffusion in the cumulative causation model affects the position of the productivity regime line through its y-intercept; but it does not affect neither the slopes of the PR and DR lines, nor the y-intercept of the latter. This means that the growth path of the productivity does not only depend on the technological characteristics of the system, but it is also affected by the prevailing type of investments and by the distribution of the productivity gains between profit earners and wage receivers.

Consequently, as the PR line shifts upward when the rate of innovation and diffusion is higher, the resulting growth rate of productivity and demand is also higher. In fact, by considering jointly the PR and DR equations, we obtain the analytical solutions of the model, i.e.:

$$AP^* = (\alpha + \beta\gamma) / (1-\beta\delta) \tag{11}$$

$$X^* = (\gamma + \delta\alpha) / (1-\beta\delta). \tag{12}$$

Such dynamic equilibrium can be stable or unstable. Similarly to Boyer’s model (1988), in order to have stable patterns of cumulative growth, the stability condition must be satisfied:

$$|\beta|<|1/\delta| \Rightarrow \beta\delta<1. \tag{13}$$

As it is clear from fig. 2, this condition requires the slope of the DR line must be higher in absolute value than the one of the PR line. Since the stability condition depends only on the coefficients that determine the slopes of the PR and DR lines, a second analytical property of the model is then the following. The inclusion of innovation and diffusion in the cumulative causation model does not affect the stability of the growth path. Technological change can thus provide with a strong initial impulse to growth, but the stability and persistence of the productivity dynamics in the long run depend on the patterns of demand and income distribution. In other words, the technology-push on the supply side must be sustained by the cumulative causation on the demand side. What matters for the stability of economic growth is then the existence of a good match between technological change and the patterns of demand growth and income distribution.

< Figure 2 here >

5. Changes in the Spanish growth regime, 1960-2001

This section presents the results of an econometric analysis of the model for the case of Spain in the period 1960-2001. The structural form of the simultaneous equations model presented in the previous sections has been estimated by using a 2sls estimator for each single equation, as a suitable technique for overidentified equations.[4] The same method has then been applied to estimate the sub-reduced forms of the model, i.e. the productivity and the demand regimes.

In testing the model, it is important to take into account the fact that many important institutional and economic changes happened in Spain between the end of the 1970s and the beginning of the 1980s: the end of Franco's regime in 1975; the economic crisis following the two oil shocks; the Moncloa agreement in 1977, with a consequent radical change in fiscal and monetary policies; the Constitutional signature in 1978; and the first stable democratic government in 1982. Such institutional and economic transformations may have determined important consequences in the stability of the model over time.

In order to test for the hypothesis of structural change in the functioning of the model between the first (1960-1980) and the second half of the period (1981-2001),[5] time dummies in multiplicative form have been included for the explanatory variables and for the constant in each equation. Although we started out with time-constant dummies (tcd) and time-slope dummies (tsd) for all the variables in all the equations, only the ones that contribute to the explanatory power (reduce the residual variance) of the model were retained in the final specification (using the general to specific method). The time dummies technique (Gujarati, 1970) allows finding out which explanatory variables (if any) may explain a structural break in the functioning of each equation over time. The results of the econometric analysis are presented in Table 1,[6] and the definitions and sources of the data used are reported in Appendix 1. In relation to Table 1, it should be observed that, when a time dummy is included in the final specification, the estimated coefficient for the first period is the algebraic sum of the one for the second period with the one for the time dummy. On the other hand, if the time dummy is not included, the estimated coefficient is the same in the two periods.

The results for the first period (1960-1980) confirm the validity of our model of cumulative causation for the Spanish case. Equation 1 shows that the growth of productivity can be mainly explained by the dynamics of demand (Kaldor-Verdoorn relationship) and, to a lesser extent, by the investment intensity (embodied technical progress).[7] Innovation and diffusion of new technologies from abroad, on the contrary, do not seem to have had an important effect on macroeconomic growth in these two decades, in which the Spanish economic system was mainly autarchic, and characterized by an industrial specialisation pattern based on traditional low-tech industries.[8]

The aggregate demand (equation 2) is mainly linked to consumption and gross investments, and only weakly to exports, thus pointing to the importance of the internal components of demand for the Spanish growth regime. Consumption (equation 3) is positively affected by the dynamics of firms' profits and the one of real wages. In equation 4, gross investments appear to be strongly determined by demand growth, thus giving support to the hypothesis of a 'Keynesian' type of investments based on the accelerator mechanism, rather than profit-led ones. The equation for export growth, in line with the similar findings of Alonso (1999), confirms the importance of taking into account both, price-competitiveness variables, as the exchange rate, and non-price competitiveness factors, such as innovation, productivity growth, and the degree of openness of the economy. The importance of latter, in particular, is mainly explained by the reforms applied in foreign trade regulations in the period, which gradually made the Spanish economy more open to foreign trade (notwithstanding the previous increase of the tariff on imports in 1960).

Turning to the distribution of productivity increases between wage receivers and profit earners, equation 6 shows that the dynamics of firms' profits does not depend on the innovation variable, whose estimated coefficient is very close to zero, while it appears to be to a larger extent dependent on the growth of productivity. This suggests that a great part of productivity gains was redistributed to capitalists and consequently consumed by them, rather than reinvested within the firms. Relatedly, this points out the still scarce attention paid by Spanish firms to the process of development of their technological capabilities and competencies through capital accumulation and innovative activities. A significant share of the productivity increases was also redistributed to wage earners (equation 7) and consumed by them. Moreover, as confirmed by empirical analysis of the Fordist growth regime for other countries in the same decades (Boyer, 1988; Vivarelli, 1995; Pini, 1996), the mechanism of wage formation on the labour market was not competitive, and the estimated coefficient for the labour market effect on real wages (via changes in the rate of unemployment) turns out to have only a very low negative impact. Finally, equation 8 shows that the dynamics of prices has been negatively affected by the growth of average productivity, but they are not significantly linked to technological innovation. Thus, confirming the model's expectation, productivity growth led to lower production costs and higher quality of existing goods, which, in a situation of market competition, have been partly translated into lower prices of final products. This mechanism, in turn, was a further stimulus to the growth of real wages, consumption and aggregate demand.[9]

Summing up the results for the first period, the patterns of distribution of the productivity gains determined a rapid growth of aggregate consumption in two different ways: by increasing the purchasing power of profit earners, and by pushing the growth of real wages of wage receivers. The dynamics of consumption sustained the one of aggregate demand, which in turn had two important consequences. First, it determined higher investments, which led to improvements in the productive processes through embodied technical progress, thus activating a cumulative interaction between investments and demand growth. Second, demand growth stimulated further growth of productivity through dynamic economies of scale and learning by doing (the Kaldor-Verdoorn mechanism).

On the whole, the Spanish growth regime in the period 1960-1980 was characterized by a cumulative causation mechanism in which the interactions between productivity and the internal components of demand (consumption and investments) were sustained by the prevailing institutional forms (in particular by a Fordist non-competitive wage formation on the labour market, and by the strong role of the State in macroeconomic policy during the last phase of Franco's regime). As it is confirmed by the estimated slopes of the productivity and demand regimes (equations 9 and 10), the good match between accumulation regime and institutional forms determined a stable but moderate growth path. However, our model also suggests that the macroeconomic performance could have been much better if the productivity growth had been sustained by a stronger rate of creation and diffusion of new technologies.

< Table 1 here >

In the second period (1981-2001), technical change turns out to be a more important factor for macroeconomic growth. In fact, the dynamics of productivity (equation 1) is positively affected by both, the creation of innovation (measured by the higher education expenditure on R&D as a percentage of GDP), and by the diffusion of new technologies from abroad (measured by the variable GAP, that is the difference between GDP per capita in US and in Spain, as a proxy for the technology-gap).[10] Moreover, the catching up process through innovation and diffusion of new technologies is strengthened by embodied technical progress, which is a further source of productivity growth. On the other hand, in line with the results of econometric analysis for other countries (Boyer, 1988; Vivarelli, 1995; Pini, 1996), important changes can be observed in the working of the Kaldor-Verdoorn relationship over time. The negative sign of its estimated coefficient, in fact, confirms the decreased importance of dynamic economies of scale for productivity growth, but it also suggests that important changes may have happened on the demand side. This is confirmed by the other equations of the structural form.

Equation 2 shows that the growth of aggregate demand still depends on the ones of investments and consumption, and much less on exports. The determinants of the internal components of demand prove to be stable over time: consumption is still positively linked to firms' profits and real wages (equation 3), and investments are still based on the Keynesian accelerator mechanism (equation 4). The equation for exports, on the other hand, shows the greater importance of the degree of openness of the Spanish economy in explaining the dynamics of its export. Although the opening up of Spanish markets to international competition constitutes an important stimulus to the improvement of competitiveness and export performance, our model suggests that the latter is still relatively less important than the internal components (consumption and investments) for the growth of aggregate demand.

This implies that the distribution of productivity increases between wage receivers and profit earners (and the consequent effects on the dynamics of the internal components of demand) has still a decisive role to play in the modern Spanish growth regime. In this respect, we observe important structural changes over time in the three equations that define the patterns of income distribution. First, equation 6 shows that the productivity gains are not redistributed to profit earners to the same extent as in the previous period, but tend to be reinvested within the firms, a trend which may have also be favoured by the level achieved by the interest rate in the period. Moreover, the greater amount of resources devoted to R&D activities and technological innovation lowers the share of profits redistributed to profit earners, and consequently consumed by them. In other words, it seems that the shift to the new technological paradigm based on ICTs requires substantial efforts on behalf of Spanish firms to implement and use the new technologies, particularly in terms of investments in physical capital and R&D activities. These efforts are likely to lead to higher productivity in the near future, but they have the immediate effect of lowering the share of profits redistributed to profit earners, and, hence, consumption and aggregate demand.

Second, equation 7 shows another important change in the patterns of distribution, suggested by the stronger negative relationship between the dynamics of real wages and that of unemployment. The higher estimated coefficient of this labour market effect points to a change in the mechanism of wage formation, which has become more competitive than it used to be in the Fordist era. The implication of this change for the Spanish economy, characterized by high rates of unemployment, is an overall erosion of real wages, and consequently a slower growth of aggregate consumption and demand. Finally, equation 8 shows a third shift in the patterns of distribution of productivity gains over time. Contrary to what happened in the first period, the estimated relationship between the dynamics of productivity and that of prices turns out to be positive. A possible interpretation of this finding is that the new ICT-based paradigm leads to higher degrees of monopoly power and imperfect market competition, particularly in fast growing medium-high and high-tech sectors, those which, to a large extent, lead the growth of aggregate productivity. In this situation, the creation of new products and the improvements in the quality of the existing ones tend to increase the price of final goods. Rapid technological advances have not been matched so far by improvements in the degree of competition in the final products markets, thus introducing a further channel of prices growth, particularly in those industries of greater technological complexity. The high rate of inflation, a serious reason of concern for the first democratic governments in Spain, is then a further factor explaining the erosion of real wages, and the consequent slowdown of consumption in the last two decades.

Summing up the findings for the second period, important changes seem to have happened in the working of the model over time. The first set of changes has to do with the supply side of the economy, and in particular with the increased rate of technical progress. Since the ‘Science Law’ and the ‘First National R&D Plan’ in the 1980s, the Spanish national system of innovation tends to determine higher rates of creation of innovation, and faster diffusion of new technologies from abroad. In a context of increased international competition since the access to the EC in 1986, private firms and policy makers have been doing a significant effort in shifting in the patterns of industrial specialisation towards activities of higher technological content, although the technological competitiveness of Spanish firms is still below the European average.

However, our results also suggest that a second set of changes, on the demand side, tends to counteract the ones observed on the supply side. The changes in the distribution of productivity gains, in fact, determine lower growth of aggregate consumption for three reasons: (i) in the attempt to catch-up with the new ICT-related activities, capitalists tend to reinvest more frequently the profits within the firms, rather than spending them in consumption goods; (ii) the high rates of unemployment lower real wages, as the mechanism of wage formation in the labour market has become more competitive; (iii) in a context characterized by rapid technological change and imperfect market competition, higher rates of inflation contribute to the erosion of real wages. Taken together, these changes in the patterns of income distribution weaken the growth of consumption and, consequently, that of aggregate demand.

In turn, the slowdown of demand has a twofold negative effect on productivity growth: it decreases the effectiveness of the Kaldor-Verdorn mechanism, and it lowers the pace of introduction of embodied technical progress through new investments. The overall effect is to hinder the cumulative causation mechanism based on the interactions between productivity and demand growth, which led the Spanish growth in the previous two decades. Both sets of changes are reflected in the shift in the slopes and y-intercepts of the productivity and demand regimes (equations 9 and 10), which still determine a stable and positive growth path.

On the whole, the supply side potential of the Spanish economy appears to be in rapid and promising development, but the slowdown of aggregate demand poses a serious constraint to its realization. Higher rates of growth of consumption, investment and demand could then provide with an additional stimulus to sustain further technological improvements and productivity growth. The effects of innovation and diffusion on the macroeconomic performance could be much stronger if they were matched by cumulative interactions between productivity and demand growth.

6. Conclusions

In the recent surge of interest in growth theorizing in the last two decades, most of the disequilibrium approaches have pointed out that economic growth is not a simple transition towards the steady state, as in the neoclassical and New Growth Theory models, but rather a complex process of evolution, transformation and qualitative change. In such a complex process, a prominent role is played by the relationships between technological and institutional changes.

While neo-Schumpeterian and evolutionary theories have so far focussed on the role of technical change on the supply side, post-Keynesian approaches have taken the demand side into greater account. This article has argued that the impacts of technological change on macroeconomic growth can be better analysed by considering both aspects, supply and demand, in the same framework.

Section 2 has then presented two complementary views on technical change and macroeconomic growth: the Regulationist-Kaldorian theory of cumulative causation, and the technology-gap approach to economic growth. The former explains economic growth in the long run in terms of the relationships between productivity and demand dynamics, which may result in cumulative causation patterns. The latter points to the importance of the national creation of innovation, and of the international diffusion of new technologies, for the catching-up process. Combining these different views in a single formalization, section 3 has presented the structural form of a model of macroeconomic growth, and section 4 has focused on its analytical properties. The model points out that what matters for economic growth in the long run is the existence of a good match between the patterns of technological change, income distribution and cumulative causation.

Section 5 has presented the results of the econometric estimation of the model for the Spanish economy during the period 1960-2001. Each equation of the simultaneous equation model has been separately estimated, and time dummies in multiplicative form have been included to test for the hypothesis of structural change in the functioning of the model between the first and the second half of the time span. The results of the estimations show that important changes have happened in the Spanish growth regime in the last four decades.

In the first period (1960-1980), Spanish economic growth appeared to be characterized by a cumulative causation mechanism in which the interactions between productivity and the internal components of demand (consumption and investments) were sustained by the prevailing institutional forms and income distribution, while the technological improvements played only a marginal role.

In the second period (1981-2001), on the other hand, the supply side potential of the Spanish economy appears to be in rapid and promising development through an increased importance of innovation and diffusion of new technologies, but the slowdown of aggregate demand poses a serious constraint to its realization. Higher rates of growth of consumption, investments and demand could then provide an additional stimulus to sustain further technological improvements and productivity growth in the long run.

Notes

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1. This is in line with the concepts of 'social capability' and 'technological congruence' developed by Abramovitz (1986 and 1994).
2. The latter relationship assumes that, *ceteris paribus*, when the degree of openness (OPEN) of a country to international trade increases, its exports will also grow faster (Pini, 1996). The idea is that the opening up of national markets to international competition constitutes an important stimulus to the improvement of export performance.
3. For a review of the main analytical properties of the model originally proposed by Boyer on Kaldorian lines, see Boyer (1988) and Boyer & Petit (1988 and 1989).
4. In large samples, 'full-information' estimators (such as 3sls) are to be preferred to 'limited-information' ones (such as 2sls) because they improve the efficiency of the estimation. However, such a result holds asymptotically, and in a relatively small sample like the one used in our econometric analysis there is no clear advantage in using a different estimator than the 2sls (Greene, 1997).
5. We have fixed 1980 as the time break for the inclusion of time dummies, so to divide our time series in two balanced sub-periods of 20 years each. Further justifications for the choice of 1980 as time break in the Spanish case can be found in the work of Rojo (1987).
6. The last row of Table 1 reports the values of the Durbin-Watson test. Note that for equations that do not include an intercept term, such as equations 1 and 5 in our model, the lower critical bound of the test is somewhat higher than the one reported in the tables of the Durbin-Watson statistic (Farebrother, 1980). In both equations, though, the upper critical bound is smaller than the values reported in the last row of table 1, so that no serial correlation is found.
7. An anonymous referee of this *Journal* suggested the use of the variable II (level of investment intensity, i.e. gross investment/GDP ratio) instead of GI (growth rate of gross investments), as in the original specification of equation 1 presented in section 3. The variable II has been found to perform better than GI in both periods, and it has thus been preferred in the final specification of equation 1.

8. As compared to the analytical model presented in section 3, the variable STRUCT (structural and institutional factors affecting the imitation process) has not been included in the final specification of the econometric model. In fact, it has been shown that such a variable is an important factor to take into account in cross-country regressions typical of technology-gap studies (Fagerberg, 1994), but it is not relevant in a time series estimation for a single country as the one considered in this article.
9. The Durbin-Watson tests for equation 7 and 8 show weak positive autocorrelation of the disturbances in both equations, as the DW values (1,03 and 0,95 respectively) are lower than the corresponding lower critical bound of the statistic (1,09). In general terms, autocorrelation of the disturbances tend to lower the efficiency of least squares estimators. This may be overcome by using 'feasible generalized least squares' estimators (FGLS), which increase the efficiency of estimates in large samples by estimating the autoregressive structure of the disturbances (Greene, 1997). However, this property of FGLS holds only asymptotically. Monte Carlo studies have shown that in situations of weak autocorrelation and relatively small samples, as the one we have in this paper, the use of FGLS estimator may lead not to a gain but to a loss of efficiency (Peracchi, 2001). This is the reason why we prefer to rely on the 2sls estimates for equations 7 and 8, rather than using a FGLS estimator to take into account such (only weak) autocorrelation.
10. The technology-gap hypothesis (Fagerberg, 1987) is commonly investigated through econometric estimation of cross-country data, where the innovation and diffusion variables are entered in the regressions with their levels at the beginning of the estimation period. Differently from this approach, however, the present article performs an investigation of technology-gap growth based on the estimation of time series for a single country, as originally suggested by Fagerberg (1994). This is the reason why the innovation and diffusion variables are entered in the regressions in equation 1 as annual growth rates. Both variables turn out with a positive sign in the estimations. The positive sign of the variable INNO suggests that the dynamics of national innovative activity has been accompanied by the growth of productivity in the period 1981-2001. The positive sign of the variable GAP indicates that the enlargement of the technology-gap of Spain vis-à-vis the US in the post-Fordist period has gradually increased the scope for catching up, and this greater scope has led to productivity growth through the international diffusion of advanced technologies.

   This dynamic interpretation of the technology-gap hypothesis in a time-series framework differs from the more traditional cross-country interpretation of this approach (e.g. in the convergence literature). Our interpretation here is consistent with the dynamic specification of all the other equations in the model, and it follows previous econometric works of Vivarelli (1995), Pini (1996), Simonetti et al. (2000), and Tancioni &

Simonetti (2002). A whole battery of additional tests has been run by introducing the innovation and diffusion variables in levels (current, and lagged 1, 2, …, 5 years) instead of their growth rates. The results of these additional tests of equation 1, available on request, suggest that the innovation and diffusion variables in the time series estimation for Spain perform better in growth rates than in their initial (or lagged) levels. On the whole, the investigation of the technology-gap hypothesis in time series analysis is an important issue for further research in the field of applied growth, and equation 1 of this paper constitutes an attempt in this direction.

References

Abramovitz, M. (1986) Catching-up, forging ahead and falling behind, *Journal of Economic History*, 46, pp.385-406.

Abramovitz, M. (1994) The origins of the Postwar Catch-up and Convergence Boom, in: J. Fagerberg et al. (Ed.) *The dynamics of technology, trade and growth* (Aldershot, Edward Elgar).

Aghion, P. & Howitt, P. (1992) A model of growth through creative destruction, *Econometrica*, 60, pp.323-351.

Alonso, J.A. (1999) Growth and the external constraint: Lessons from the Spanish case, *Applied Economics*, 31, pp.245-253

Amable, B. (1993) Catch-up and convergence in a model of cumulative growth, *International Review of Applied Economics*, 7, pp.1-25.

Boyer, R. (1988) Formalizing growth regimes, in: G. Dosi et al. (Ed.) *Technical change and economic theory* (London, Pinter).

Boyer, R. (2003) From the diversity of capitalisms to the variety of business models. A survey of the main findings in 'Regulation Theory', paper presented at the conference *National Business Systems in the New Global Context: Competing Explanations of Economic Development and Organisations*, Oslo, May 2003.

Boyer, R. & Petit, P. (1988) The cumulative growth model revisited, *Political Economy. Studies in the Surplus Approach*, 4(1), pp.23-44.

Boyer, R. & Petit, P. (1989) Kaldor's growth theories: past, present and prospect for the future, in: E. Nell (Ed.) *Nicholas Kaldor and the mainstream economics* (London, Macmillan).

Cappelen A., Castellacci, F., Fagerberg J. & Verspagen, B. (2003) The impact of regional support on growth and convergence in the European Union, *Journal of Common Market Studies*, 41 (4), pp.621-644.

Castellacci, F. (2002) Technology-gap and cumulative growth: models and outcomes, *International Review of Applied Economics,* 16 (3), pp.333-346.

Castellacci, F., Grodal, S., Mendonca, S. & Wibe, M. (2005) Advances and challenges in innovation studies, *Journal of Economic Issues*, XXXIX, pp. 91-121.

Cornwall, J. (1977) *Modern Capitalism, its Growth and Transformations* (London, Martin Robertson).

Dixon, R. & Thirlwall, A.P. (1975) A model of regional growth-rate differences on Kaldorian lines, *Oxford Economic Papers*, 27, pp.201-213.

Fagerberg, J. (1987) A technology gap approach to why growth rates differ, *Research policy*, 16, pp.87-99.

Fagerberg, J. (1988) International competitiveness, *Economic Journal*, 98, pp.355-374.

Fagerberg, J. (1994) Technology and International differences in growth rates, *Journal of Economic Literature*, 32, pp.1147-1175.

Fagerberg, J. & Godinho, M. M. (2004) Innovation and Catching-up, in: J. Fagerberg, D. C. Mowery & R. R. Nelson (Eds.) *The Oxford Handbook of Innovation* (Oxford, Oxford University Press).

Farebrother, R. (1980) The Durbin-Watson test for serial correlation when there is no intercept in the regression, *Econometrica*, 48, pp.1553-1563.

Fonfría, A., Díaz, C., & Álvarez, I. (2002) The role of technology and competitiveness policies: a technology-gap approach, *Journal of Interdisciplinary Economics*, 13, pp.223-242.

Freeman, C., Clark, J. & Soete, L. (1982) *Unemployment and technical innovation* (London, Pinter).

Gerschenkron, A. (1962) *Economic Backwardness in Historical Perspective* (Cambridge, Harvard University Press).

Greene, W. (1997) *Econometric Analysis*, 3rd edn (Upper Saddle River, N.J., Prentice Hall)

Gujarati, D. N. (1970) Use of dummy variables in testing for equality between sets of coefficients in two linear regressions: a note, *American Statistician*, 24(1), pp.50-52.

Kaldor, N. (1957) A model of economic growth, *Economic Journal*, 67, pp.591-624.

Kaldor, N. (1981) The role of increasing returns, technical progress and cumulative causation in the theory of international trade and economic growth, *Economie Appliquee*, 34(4), pp.593-617.

Ledesma, M.A. (2002) Accumulation, Innovation and Catching-up: an Extended Cumulative Growth Model, *Cambridge Journal of Economics*, 26(2), pp.201-216.

Lucas, R. (1988) On the mechanics of economic development, *Journal of Monetary Economics*, 22, pp.3-42.

Myrdal, G. (1957) *Economic Theory and Underdeveloped Regions* (London, Duckworth).

Nelson, R. & Winter, S. (1982) *An Evolutionary Theory of Economic Change* (Cambridge, M.A., Harvard University Press).

Peracchi, F. (2001) *Econometrics*, Wiley, Chichester.

Pini, P. (1996) An integrated model of cumulative causation: empirical evidence for nine OECD countries, 1960-1990, *Labour*, X(1), pp.93-150

Romer, P. (1986) Increasing returns and long-run growth, *Journal of Political Economy*, 94, pp.1002-1037.

Romer, P. (1990) Endogenous technological change, *Journal of Political Economy*, 98, pp.71-102.

Rojo, L.A. (1987) La crisis en la economía española 1973-1984, in: J. Nadal, A. Carreras & C. Sudriá (Eds.) *La Economía Española en el Siglo XX. Una Perspectiva Histórica* (Barcelona, Ariel).

Simonetti, R., Taylor, K. & Vivarelli, M. (2000) Modelling the employment impact of innovation: do compensation mechanisms work?, in: M. Pianta & M. Vivarelli (Eds.) *The Employment Impact of Innovation: Evidence and Policy* (London, Routledge).

Solow, R. (1956) A contribution to the theory of economic growth, *Quarterly Journal of Economics*, 70, pp.65-94.

Tancioni, M. & Simonetti, R. (2002) A macroeconomic model for the analysis of the impact of technological change and trade on employment, *Journal of Interdisciplinary Economics*, 13, pp.185-221.

Targetti, F. & Foti, A. (1997) Growth and productivity: a model of cumulative growth and catching-up, *Cambridge Journal of Economics*, 21, pp.27-43.

Verspagen, B. (1991) A new empirical approach to catching up or falling behind, *Structural change and economic dynamics*, 2(2), pp.359-380.

Verspagen, B (1993) *Uneven Growth Between Interdependent Economies: Evolutionary View on Technology-gaps, Trade and Growth* (Avebury, Aldershot).

Vivarelli, M. (1995) *The Economics of Technology and Employment. Theory and Empirical evidence* (London, Edward Elgar).

Appendix 1: Definition, source, and measurement of the variables used in the econometric model

Variable	Measured by	Source
AP : Average productivity	Ratio between GDP and civilian employment, constant 1995 $ PPP per thousand of people, annual percentage rates of change	OECD (Annual National Accounts, Main Economic Indicators), and own elaboration.
GI : Gross investments	Gross fixed capital formation, constant 1995 $ PPP, annual percentage rates of change	OECD (Annual National Accounts), and own elaboration.
II: Investment intensity	Gross fixed capital formation, constant 1995 $ PPP, divided by GDP, constant 1995 $ PPP	OECD (Annual National Accounts), and own elaboration.
X : Demand	GDP, constant 1995 $ PPP, annual percentage rates of change	OECD (Annual National Accounts), and own elaboration.
INNO: national innovative activity	Higher education expenditure on R&D as a percentage of GDP, annual percentage rates of change	OECD (Main Science and Technology Indicators), and own elaboration.
GAP : Technology-Gap with the US	Difference between GDP per capita in USA and in Spain, constant 1995 $ PPP, annual percentage rates of change	OECD (Annual National Accounts), and own elaboration.
PROF : Profits	Profits of firms: “operating surplus”, constant 1995 $ PPP, annual percentage rates of change	INE (Spanish National Statistical Institute), and own elaboration.
RW: Real wage	Real wage per employee, annual percentage rates of change	OECD (Main Economic Indicators), INE, and own elaboration.
C : Consumption	Private consumption, constant 1995 $ PPP, annual percentage rates of change	OECD (Annual National Accounts), and own elaboration.
EXP : exports	Exports of goods and services, constant 1995 $ PPP, annual percentage rates of change	OECD (Annual National Accounts), and own elaboration.
OPEN : Openness of the economy	Degree of openness of the economy: (Imports+EXP)/X, constant 1995 $ PPP, annual percentage of change	OECD (Annual National Accounts), and own elaboration.
EER : Exchange rate	Effective exchange rate, annual percentage of change	OECD (Main Economic Indicators), and own elaboration.
U: Unemployment	Unemployment rate, annual percentage rates of change	OECD (Main Science and Technology Indicators), and own elaboration.
P: Prices	Consumption price index, annual percentage rates of change	INE (Spanish National Statistics Institute), and own elaboration.

Figures

Fig. 1: A dynamic model of innovation, diffusion and cumulative causation

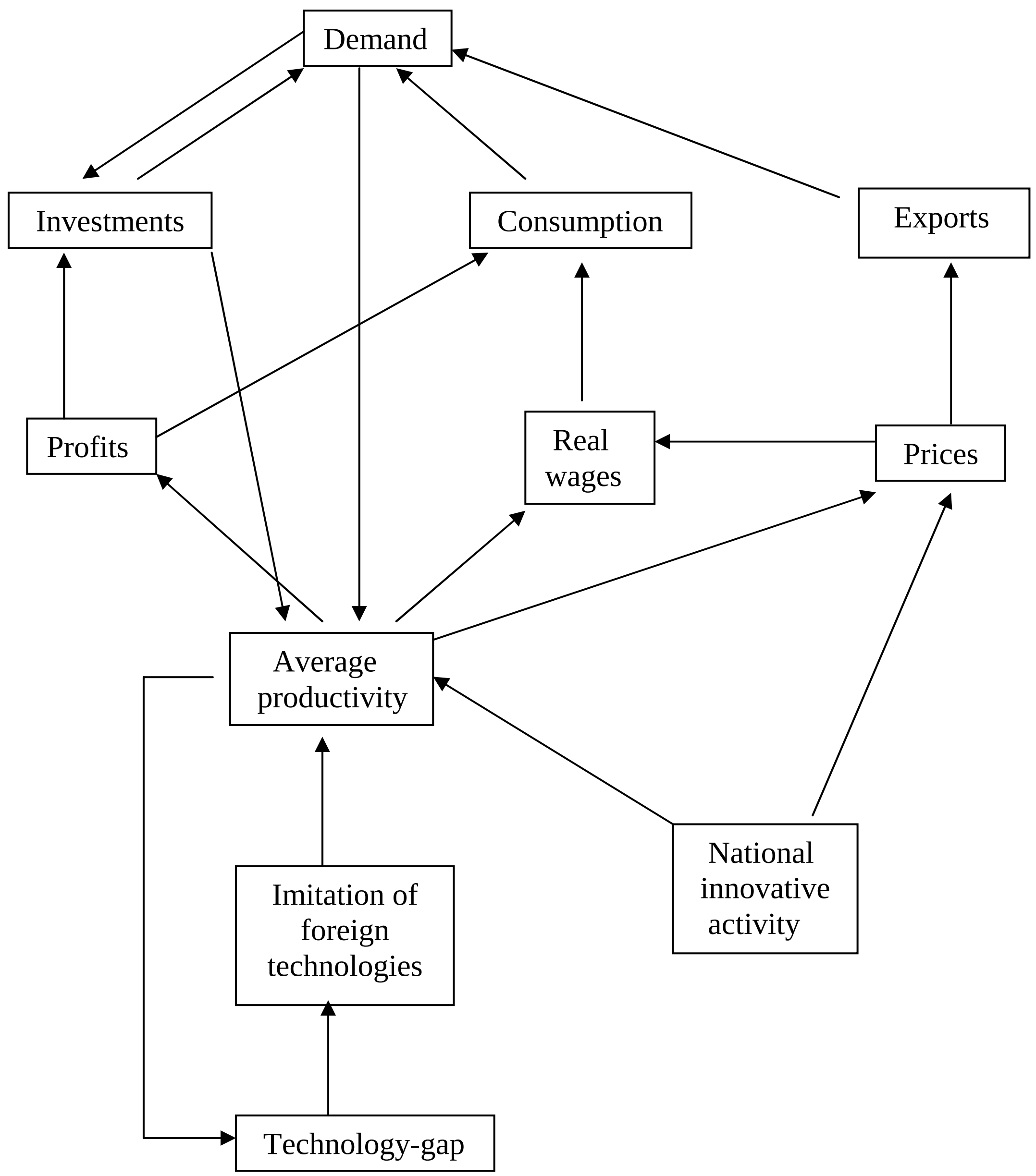

Fig. 2: growth path determined by the productivity regime (PR) and the demand regime (DR): stable (a) and unstable (b) cases.

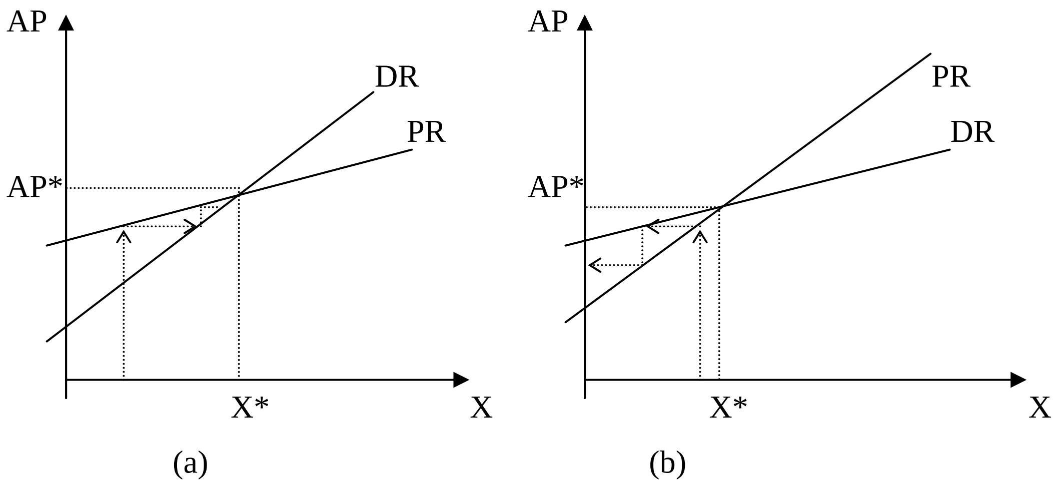

Table 1: Results of 2sls estimations of the model for the Spanish economy, 1960-2001*

	Eq. 1 **AP**	**Eq. 2** **X**	**Eq. 3** **C**	**Eq. 4** **GI**	**Eq. 5** **EXP**	**Eq. 6** **PROF**	**Eq .7** **RW**	**Eq. 8** **P**	**Eq. 9** **PR**	**Eq. 10** **DR**
Constant		0,01 (3,13)	0,02 (2,43)	-0,06 (4,44)		0,06 (5,23)	-0,10 (6,15)	0,04 (2,82)	0,03 (6,87)	0,04 (8,86)
Tcd**			0,02 (2,45)	-0,04 (2,68)		-0,10 (2,66)	-0,08 (2,47)	0,19 (4,28)	-0,02 (2,22)	-0,06 (4,79)
AP					1,04 (4,19)	-1,07 (1,63)	2,87 (3,82)	1,56 (2,11)		-0,96 (4,05)
AP tsd						2,33 (2,55)		-4,05 (3,83)		2,36 (7,42)
X	-0,44 (2,56)			3,15 (9,19)					-0,67 (4,42)	
X tsd	1,08 (8,09)								1,31 (7,02)	
C		0,43 (4,55)								
GI		0,22 (8,09)								
II	0,07 (2,04)									
EXP		0,04 (1,62)								
PROF			0,33 (2,25)	0,08 (0,34)						
RW			0,18 (2,03)							
INNO	0,16 (2,64)				0,06 (2,78)	-0,25 (2,36)		-0,001 (0,06)		
INNO tsd	-0,15 (2,75)					0,27 (2,54)				
GAP	0,21 (2,55)									
GAP tsd	-0,21 (2,02)									
EER					0,21 (2,33)					
OPEN					1,21 (7,68)					
OPEN tsd					-0,79 (3,36)					
U							-0,41 (3,53)			
U tsd							0,39 (3,15)			
R^2 **(Adj. R^2)**	0,92 (0,90)	0,88 (0,87)	0,36 (0,31)	0,77 (0,75)	0,83 (0,80)	0,31 (0,21)	0,36 (0,29)	0,40 (0,33)	0,81 (0,80)	0,72 (0,69)
DW test	1,95	1,63	2,00	2,25	2,52	2,29	1,03	0,95	1,88	1,42

(*) t-statistics in brackets
(**) Tcd = time constant dummy; tsd = time slope dummy