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Abstract:

The role of capital stock in measuring resilience is investigated. Based on the current and potential growth paths we propose new indexes to better measure the characteristics associated with resilience: adaptability and resistance to shocks. The dynamics of capital instead of employment is used as a proxy for economic welfare, considered ideal to represent the evolution of economic systems. The two series of capital stock for the US and Spanish economies, associated with the short-run and the long-run trajectories, allows us to empirically compute the indexes and draw conclusions about their ability to resist shocks and absorb their effects.

Keywords: Adaptability, Capital, Growth, Resilience, Resistance.

JEL classification: E22, O10, R11.

1 Introduction

Nowadays the concept of resilience plays an important role in the field of social sciences. Economics in particular, in the wake of the Great Recession began to show a growing interest in the subject. At this point, the areas of economics most involved in the study of resilience are environmental economics, economic geography and regional economics. These do not belong to the mainstream of the economy, but they are important subdisciplines where the expansion of the frontier of knowledge requires the cooperation of specialists from different areas of research. In other words, they call for multidisciplinarity.

Actually, the concept of resilience has been adapted from natural sciences, specially from ecological literature where resilience is the capacity of an ecosystem to respond to a natural perturbation, to an anthropogenic[1] disturbance or to any destabilizing influence, by maintaining the previous state, resisting changes and damages and, if necessary, recovering quickly from them. Once introduced in social sciences, resilience has still received different meanings like the ability of a system to maintain services, to adapt in the face of adverse conditions, to absorb shocks without suffering complete deformation and failure, or to resist changes.

Given the areas of economics concerned with the study of resilience, the usual question that researchers try to answer is about the ability of an economic system to respond to some particular natural or human-made negative shock. But, what is meant by "to respond to"? According to Hill et al. (2008), it is the extent to which an economy is able to maintain a pre-existing path or state. This could be interpreted as the ability of the system to return to its previous trajectory or to avoid being thrown out of its trajectory. The latter would require avoiding or withstanding the shock with little or no adverse impact.

Resilience was originally introduced in relation to disasters. Consequently, most of the recent studies, like Briguglio et al. (2008), Simmie and Martin (2010), Fingleton et al. (2012), Hallegate (2014) or Caldera-Sánchez et al. (2016), focus on isolated and negative exogenous shocks and analyze the reaction of the system in terms of the economic performance. However, an economy (aggregate, regional or whatever) is continuously being affected by a large number of shocks of many types (supply shocks or demand shocks, recessionary or expansive) and of different intensities. It is in this more general context where resilience should be evaluated. Unfortunately, there is no widely accepted methodology among researchers on how to measure economic resilience. Most empirical works, taking as reference Martin (2012) that suggests to use data on aggregate output and employment, analyze the levels and the rates of growth of these variables during recession and postrecession periods. Many of them still focus on

[1] Ecosystems can be negatively affected by human activities that reduce biodiversity, overexploit natural resources, pollute, misuse the land, and are responsible for global warming.

the concept of regional resilience and confine their quantitative studies to the movements in employment rather than output.[2] Eventually, they have contributed to generalize the rate of growth of employment in the region relative to the national average as the standard indicator for regional resilience evaluation.

In order to study the regional economic resilience, it is necessary to clarify before the concept of region. In the literature the region is usually defined as a territorial unit, characterized by certain specific economic conditions. A region is a system of political and economic processes, including productive, demographic and employment structures as well as institutions, which are more or less constant through time and space. However, in this paper our study of resilience is more general. Our concepts and indexes for resilience measurement do not depend on a comparison between regions, but can be applied to a particular geographic area, region or nation, with enough economic entity to be distinguished from others, adjacent or not.

Even so, the aim of this paper is not to fill the lack of a commonly accepted theory of economic resilience, which could answer the question of why some economies are resilient while others are not. Our purpose here is not to explain resilience, which is left for future research, but to measure it at the aggregate as well as at the regional level. To do this, we first deal with the definition of resilience. We identify the features of adaptation-absorption and resistance to shocks as the cornerstone of the definitions at hand. From the different alternatives, we focus on the definition arising from engineering and physics which better fits to economics and, in particular, to economic dynamics and growth models.

The paper is organized as follows. Section 2 provides the conceptual framework to interpret economic resilience and states the connection with the evolution of capital stock, instead of such of employment that is the more commonly used in empirical studies. We address the question of why is important to use the capital stock as a proxy for features like the size and shape of an economic system. We also put forward the link between economic welfare and the dynamics of capital stock to introduce the referential measure of perfect resilience in terms of the latter. In Section 3 we propose the indexes that better account for the cases of imperfect resilience. They are designed to measure the dimensions of resilience: adaptability and resistance, based on the short-run and long-run capital stock trajectories. In Section 4 we provide the results of an exercise where we apply the concepts and instruments proposed in previous sections to the US and Spanish data. Our study summarizes the entire sample period, 1960-2011 for US and 1964-2011 for Spain, leaving aside the dynamic application of the indexes. Consequently,

[2] It is well known Martin's opinion that "*a regional or local economy may resume output growth following a recession without a corresponding recovery in employment, thereby creating major problems of adjustment for local unemployed workers. How far and in what ways regional employment rebounds following recession is thus arguably a more insightful indicator of a regional economy's resilience*".

what we offer is a comparative structural and static characterization of the two economies with respect to resilience. Section 5 concludes.

2 Economic resilience and capital stock

There is not a definition of economic resilience generally accepted, as well as there is not a theory of economic resilience as such (CARRI, 2013; Palekiene et al., 2015). But neither is there a single empirical measure of economic resilience universally agreed. In physics and engineering resilience is usually defined as the capacity of a system to absorb the impact of a significant disturbance and reorganize in order to preserve the same function, structure, and identity. It also refers to the time required for a system to return to an equilibrium following a perturbation. In economics it has been assumed that resilience is the ability of the system to adapt and recover quickly its original size and structural shape, after a deformation caused by some among a wide variety of shocks. But it is also the ability to resist the shocks themselves and avoid being expelled from its previous equilibrium trajectory. Two main attributes of economic systems emerge from the aforementioned that take us to the core of the concept of economic resilience: the adaptation-absorption capacity and the resistance ability to stay close to a potential equilibrium path.

There are three main perspectives to address the concept of resilience developed in Martin (2012): engineering, based on the existence of a unique dynamic equilibrium path; ecological, which admits the existence of multiple equilibria; and adaptive, founded in complex adaptive systems theory. The definition of economic resilience outlined in the previous paragraph, which is the definition that we will use in this paper, does correspond to the first of the three above perspectives. Consequently, we use a dynamic concept of resilience grounded in physical sciences that shows a strong connection with the elements of modern dynamic macroeconomics and the theory of economic growth. One feature of these new developments in economic theory that we will retain in our study of economic resilience is the interest in the relationship between short-run and long-run dynamics. That is, between transitional dynamics and long-run growth.[3]

To address the measurement issue, we must take into account that resilience is a property of systems that should be analyzed in terms of its performance. In the case of an economic system we have to choose the variable that better represents it. In our opinion, the most suitable candidate for the economy's performance indicator is social welfare and, given that

[3]Instead, Pike et al. (2010) highlights the weaknesses of the equilibrium-based approach, while in Simmie and Martin (2010) we find a proposal to go beyond the standard use of the concepts of equilibrium, unique or multiple, and dynamic stability. These authors emphasize the concepts of structural instability and bifurcation to analyze resilience from an evolutionary perspective. They focus on the ability of a system to adapt from one regime of stability to another in a context characterized by strongly non-linear dynamics.

resilience is a dynamic property, the indicator should be the social welfare index evaluated along the economy's dynamic equilibrium trajectory.

As it is usual in the standard formulation of optimal growth models, the objective functional is an expression of the social welfare function W. This one could be Benthamite (classical utilitarianism) or Millian (average utilitarianism) depending on the weight λ of total population N, but it is always an intertemporal utility function, with constant discount rate ρ, that is assumed to be time additively separable. It is based on an instantaneous utility function U that represents households' preferences defined over per capita consumption c,

$$W(\tau) = \int_{\tau}^{+\infty} U(c(s))\, N(s)^{\lambda}\, e^{-\rho(s-\tau)} ds. \tag{1}$$

Moreover, in the context of intertemporal optimization models we cannot forget the dynamic resources constraint. This one represents the changes of capital stock K that depends on the evolution of consumption C. But it also shows how the motion of capital determines the dynamics of output Y,

$$Y(\tau) = \dot{K}(\tau) + \delta(\tau) K(\tau) + C(\tau). \tag{2}$$

On the other hand, the size and shape or any other quasi-permanent feature of an economic system is better represented by a structural variable like the capital stock than by a flow like the labor input or the unemployment rate. This is because the latter tends to overreact more than the capital stock face to marginal changes in the economic environment. Employment usually obeys conjunctural movements.[4] Thus, we will consider the growth path for capital stock, in representation of the dynamic behavior of the economy, as a good proxy for the evolution of economic welfare and the system's performance in the medium and long term.

Now, once we have concluded on the variable that will be used to measure the state of the economy and summarize the relevant characteristics for resilience, we have still to decide on whether we take the levels or the rates of growth as reference for computations. The usual specification of growth models gives rise to exponential solution trajectories. Consequently, we will assume that trajectories are ideally represented in continuous time and that they adopt an exponential form. This is highly consistent with the representation of an economy evolving close to a long-run trajectory, which is commonly identified as the balanced growth path of that economy. In the long-run the levels of the relevant variables grow at a positive constant

[4] The empirical literature that investigates regional resilience is based on the series of the current level of employment. As Fingleton et al. (2012) pointed out, researchers are mainly interested in studying resistance to and recovery from recessions. Their standard computations include: i) the regional percentage decline in employment relative to the national percentage decline in employment during the recession period (resistance index); ii) the postrecession percentage growth in employment in a region relative to the percentage growth in national employment until the onset of the next recession (recovery index); iii) the number of quarters elapsed until the previous highest employment levels are recovered (recovery index).

rate of growth. Then, we can study the characteristics of the economic system, and implement comparative analyses, just observing the current and long-run rates of growth instead of the levels.

In this context, the $KL(t)$ variable will represent the level of capital stock along the balanced growth path in the long-run. This variable is assumed that follows a long-run trajectory characterized by a constant rate of growth, $\bar{\gamma}_{KL}$, which applies at every point of the path

$$KL(t) = KL(t_0) \cdot \exp\left\{ \int_{t_0}^{t} \bar{\gamma}_{KL} d\tau \right\}. \tag{3}$$

Conceptually, the long-run values associated to this path represent the values that prevail either in the absence of any shock or after the effects caused by different shocks have been completely interiorized.

The $KS(t)$ variable will represent the level of capital stock along the transition in the short-run. This variable evolves according to the trajectory

$$KS(t) = KS(t_0) \cdot \exp\left\{ \int_{t_0}^{t} \gamma_{KS}(\tau) \, d\tau \right\}, \tag{4}$$

where $\gamma_{KS}(t)$ is the current rate of growth of capital stock.

Resilience is a property of the economic system that has to do with its capacity to keep the economy's growth path as close as possible to the potential one. Resilience is in fact a characteristic of economies that may be analyzed by studying the relationship between the two variables $KS(t)$ and $KL(t)$. The $KS(t)$ variable is assumed that moves in the short-run subject to any shock experienced by the economy. Shocks that either throw the economy off its growth path or have the potential to throw it off its growth path but do not. Here, different patterns may be found for $KS(t)$: it could monotonically explode away; it could fluctuate around the long-run levels $KL(t)$, drawing either explosive, dampened or regular oscillations; but it also could remain stuck to the long-run levels with no transitional dynamics.

For the sake of simplicity we will consider that the two series of capital stock start from the same initial value, $KS(t_0) = KL(t_0)$. Then, the trivial case of **perfect resilience**[5] may be associated with the equality $KS(t) = KL(t)$ $\forall t$. In this extreme case none of the multiple and repeated shocks experienced by the economy diverts the short-run evolution of the capital stock from the corresponding long-run values. Consequently, from (3) and (4) we get the result of perfect resilience in terms of the growth rates,

$$\int_{t_0}^{t} \left(\gamma_{KS}(\tau) - \bar{\gamma}_{KL} \right) d\tau = 0 \qquad \forall t, \tag{5}$$

[5] We need an absolute, a reference for the coming computational definitions of resilience, adaptability and resistance. Our choice has been to define the corresponding extreme cases associated with the perfectness of each of the above concepts. Subsequently, we can use them as a pattern for comparisons.

because

$$\gamma_{KS}(t) = \bar{\gamma}_{KL} \qquad \forall t. \tag{6}$$

3 Imperfect resilience: indexes of adaptability and resistance

Now, we shall inspect the alternative cases of nonresilience in which, as a consequence of some shock(s), the capital stock moves away from the long-run trajectory, $KS(t) \neq KL(t)$ from t_0 onwards. In particular, the series $KS(t)$ can explode, in which case $KS(t) \neq KL(t)$ forever and $\gamma_{KS}(t) \neq \bar{\gamma}_{KL}$ $\forall t > t_0$. But also we can observe the more interesting case in which after some finite interval of time, at t_1 for example, the series $KS(t)$ reaches again the long-run value of the variable $KL(t)$, that is $KS(t_1) = KL(t_1)$.[6]

It is the latter case which deserves more attention because we could differentiate between the capability of adaptation and the success of absorption on the one hand, and the resistance to shocks on the other. Leaving aside for the moment the property of resistance, we can say that the time elapsed from t_0 to t_1 is the amount of time required by the economy to completely absorb the effects caused by shocks or to become fully adapted to them. This clearly involves the speed with which the economic system returns to its long-run balanced growth path after the shock.

Given that $KS(t)$ and $KL(t)$ match to each other at t_0 and t_1, we can establish the result $\ln\left(\frac{KS(t_1)}{KS(t_0)}\right) = \ln\left(\frac{KL(t_1)}{KL(t_0)}\right)$ and, given the exponential form introduced in (3) and (4), we get

$$\int_{t_0}^{t_1} \left(\gamma_{KS}(\tau) - \bar{\gamma}_{KL}\right) d\tau = 0. \tag{7}$$

Consequently, we can introduce the extreme case of **complete adaptation-absorption** based on this result. It is said that the economy is completely adapted to the effects of a shock after $(t_1 - t_0)$ periods if

$$\mathit{Average}\ \left\{\gamma_{KS}(t) - \bar{\gamma}_{KL}\right\} = \frac{1}{(t_1 - t_0)} \int_{t_0}^{t_1} \left(\gamma_{KS}(\tau) - \bar{\gamma}_{KL}\right) d\tau = 0. \tag{8}$$

Instead of that, given that the economy is continuously perturbed by shocks that superpose, we rather expect to find partial adaptation while the absorption is in the way of being completed. In such a case the sample mean of the difference between the short- and long-run rates of growth

[6] It is probably true that, as in most economic models with a balanced growth path, the variable $KS(t)$ will eventually converge to $KL(t)$, $\lim_{t\to\infty} KS(t) = \lim_{t\to\infty} KL(t)$. However, this property of convergence at infinity cannot be used to characterize resilience in mathematical terms because in our context $\lim_{t\to\infty} KL(t) = \infty$, which poses a major problem to handle it algebraically.

of capital stock, calculated for any interval of $(t - t_0)$ periods, would be different from zero. We consider that it is possible to use this non-null value as the basis for the measure of the incomplete degree of adaptability. However, we have to take into account that, as it is shown in (7), every time that $KS(t)$ cuts $KL(t)$ the accumulated value of the difference between the rates of growth becomes zero. This could imply that a unique non-null value of the sample mean might be associated with two very different adaptive processes: one that adapts slowly and rarely crosses and other that adapts quickly and crosses repeatedly.

This possibility leads us to introduce a correction for avoiding indeterminacy and better conclude about the degree of adaptability. We propose as the *index of adaptability* (AI)

$$AI(t) = \frac{1}{(1+n)} \frac{1}{(t-t_0)} \int_{t_0}^{t} \left(\gamma_{KS}(\tau) - \bar{\gamma}_{KL} \right) d\tau. \tag{9}$$

Here, frequency $n \in [0, \infty[$ represents the number of times that the $KS(t)$ series crosses the $KL(t)$ series, beyond the initial period in which they are equal by assumption. According to (9), the closer the absolute value of $AI(t)$ is to zero, the greater the degree of adaptability of the economic system.

Finally, we come back to the property of resistance. We find the trivial case of **perfect resistance** associated with the equality $KS(t) = KL(t)$ $\forall t$. This implies that we can also identify this extreme case with the result

$$\ln (KS(t) / KL(t)) = 0 \qquad \forall t. \tag{10}$$

Consequently, imperfect resistance will come associated to non-null values of the difference of logarithms of the two series of capital stock. One way of defining the different degree of imperfect resistance is by calculating the variance of the difference of logarithms, which we propose as the *index of resistance* (RI). Of course, the closer the variance is to zero, the greater the degree of resistance to shocks shown by economic systems. Under the ideal representation of trajectories in the exponential form, and given the initial equality $KS(t_0) = KL(t_0)$, we have

$$RI(t) = Variance \ \{\ln KS(t) - \ln KL(t)\} = Variance \ \left\{ \int_{t_0}^{t} \left(\gamma_{KS}(\tau) - \bar{\gamma}_{KL} \right) d\tau \right\}. \tag{11}$$

These two indexes of adaptability and resistance are complementary to each other. Moreover, it is apparent that they can not even be ranked hierarchically. In consequence, although they represent the two main conceptual dimensions of resilience, we can not unify them to provide a unique and one-dimensional quantitative statistic for resilience. Any study on resilience implemented according to the approaches of this work must necessarily compute the two indexes AI and RI separately, and try to manage them in the best way to correctly conclude about the resilience in the aggregate.

4 The indexes at work

The database for the series used in this paper may be found in Escribá-Pérez et al. (2018, 2019). Our empirical analysis is based on the US and Spain data for the series of gross investment, depreciation and capital stock. Given the series for gross investment, I_t^G, the annual series for the short-run capital stock, $KS(t)$, does correspond to the *economic measure* of productive capital called K_t^*, being δ_t^* its associated *economic* depreciation rate, and evolving according to

$$K_t^* = I_t^G + (1 - \delta_t^*) K_{t-1}^*. \tag{12}$$

On the other hand, the annual series for the long-run capital stock, $KL(t)$, refers to the *statistical measure* of productive capital called K_t, being δ_t its associated *statistical* depreciation rate, and evolving according to

$$K_t = I_t^G + (1 - \delta_t) K_{t-1}. \tag{13}$$

The latter does correspond to capital values generated with the Perpetual Inventory Method, according to which it is assumed a fixed service life for each different type of capital goods. The variability of the depreciation rate reflects mechanically the changes in capital composition. The former is obtained according to an algebraic algorithm that allows for the endogenous measurement of the depreciation rate and the capital stock, on the basis of agents' optimal decisions once transformed into market valuations.

According to what has been said in the previous section, to study economic resilience we adopt a standard framework commonly associated with economic growth theory. That is, in discrete terms the levels of the relevant variables evolve geometrically following the paths

$$K_t = K_{t_0} \cdot \prod_{t_0}^{t} \left(1 + \bar{\gamma}_K\right), \tag{14}$$

$$K_t^* = K_{t_0}^* \cdot \prod_{t_0}^{t} \left(1 + \gamma_{K_\tau^*}\right). \tag{15}$$

where $\bar{\gamma}_K$ is the constant long-run rate of growth of capital stock along the balanced growth path, and $\gamma_{K_\tau^*}$ is the variable or current rate of growth of capital stock in the short-run along the transition.

We shall now conform the *index of adaptability* (9) to the discrete framework,[7] which trans-

[7] Here we use the following transformations $\ln\left(\prod_{t_0}^{t}(1+x_\tau)\right) - \ln\left(\prod_{t_0}^{t}(1+y_\tau)\right) = \sum_{t_0}^{t} \ln\left(\frac{1+x_\tau}{1+y_\tau}\right) \simeq \sum_{t_0}^{t}(x_\tau - y_\tau)$.

forms into

$$AID_t = \frac{1}{(1+n)}\frac{1}{(t-t_0)}\sum_{t_0}^{t}\left(\gamma_{K_\tau^*} - \bar{\gamma}_K\right). \tag{16}$$

The above expression may be rewritten as the product of two terms where the first one is always positive, and contributes to modify the second one by reducing its absolute value. The second term determines the sign of the index,

$$AID_t = \left(\frac{1}{1+n}\right)\left(\left(\frac{1}{(t-t_0)}\sum_{t_0}^{t}\gamma_{K_\tau^*}\right) - \bar{\gamma}_K\right). \tag{17}$$

The first term does not affect the sign of the adaptability index that is negative or positive depending on whether the average value of the current rates of growth experienced by the capital stock K^* during the sample period is lower or higher than the constant rate of growth associated with the capital stock K. In any case, the important thing to interpret the result of this index is not the sign, but how far it is from zero, i.e. its absolute value. As in the continuous case, the closer the absolute value of AID_t is to zero, the greater the degree of adaptability of the economic system.

From (12) and (13) we get $\frac{K_t^*-K_{t-1}^*}{K_{t-1}^*} = \frac{I_t^G}{K_{t-1}^*} - \delta_t^* = i_t^* - \delta_t^*$ and $\frac{K_t-K_{t-1}}{K_{t-1}} = \frac{I_t^G}{K_{t-1}} - \delta_t = i_t - \delta_t$. These expressions suggest the direct substitution of $\gamma_{K_\tau^*} - \bar{\gamma}_K = i_\tau^* - \delta_\tau^* - i_\tau + \delta_\tau$ in the index of adaptability (16). In such a case we would have a disaggregation of the index into two components: the *depreciation component* that is related to the difference between statistical and economic depreciation rates, and the *investment component* that is related to the difference between economic and statistical investment rates,

$$AID_t^d = \frac{1}{(1+n)}\frac{1}{(t-t_0)}\sum_{t_0}^{t}(\delta_\tau - \delta_\tau^*) + \frac{1}{(1+n)}\frac{1}{(t-t_0)}\sum_{t_0}^{t}(i_\tau^* - i_\tau). \tag{18}$$

However, this procedure does not agree with our theoretical approach. Conceptually $\bar{\gamma}_K$ should be the constant growth rate associated with the geometric specification of the long-run path for capital stock, rather than the current rate of growth of the statistical measure of capital stock. Consequently, before we implement empirically the discrete index of adaptability, there is an important remark to be done. That is, since it is not possible to know the exact value of such theoretical parameter, we will numerically compute the constant rate of growth as the sample mean $\bar{\gamma}_K = \frac{1}{T}\sum_{t=1}^{T}\frac{K_t-K_{t-1}}{K_{t-1}} = \frac{1}{T}\sum_{t=1}^{T}(i_t - \delta_t)$. Then, the above specification of the index in (18) requires a correction. Given that $\gamma_{K_\tau^*} - \bar{\gamma}_K = i_\tau^* - \delta_\tau^* - \frac{1}{T}\sum_{s=1}^{T}(i_s - \delta_s) = \delta_\tau - \delta_\tau^* + i_\tau^* - \frac{1}{T}\sum_{s=1}^{T} i_s - \delta_\tau + \frac{1}{T}\sum_{s=1}^{T}\delta_s$, next we show how the adaptability index (16) can be correctly decomposed in the components that substitute the investment and depreciation rates for the rates of growth of the two involved capital stocks,

$$A\tilde{I}D_t^d = \frac{1}{(1+n)}\frac{1}{(t-t_0)}\sum_{t_0}^{t}(\delta_\tau - \delta_\tau^*) + \frac{1}{(1+n)}\frac{1}{(t-t_0)}\sum_{t_0}^{t}(i_\tau^* - \tilde{\imath}_\tau) \equiv AID_t, \tag{19}$$

where $\tilde{\imath}_\tau = \frac{1}{T}\sum_{s=1}^{T} i_s + \left(\delta_\tau - \frac{1}{T}\sum_{s=1}^{T}\delta_s\right)$.[8]

The above expression may be rewritten as the product of two terms where the first one makes apparent the role of the frequency n, while the second one plays the important role of bringing to the foreground the sign of the *depreciation* and *investment components*,

$$AID_t = \left(\frac{1}{1+n}\right)\left(\left(\frac{1}{T}\sum_{s=1}^{T}\delta_s - \frac{1}{(t-t_0)}\sum_{t_0}^{t}\delta_\tau^*\right) + \left(\frac{1}{(t-t_0)}\sum_{t_0}^{t} i_\tau^* - \frac{1}{T}\sum_{s=1}^{T} i_s\right)\right) \equiv A\tilde{I}D_t^d. \tag{20}$$

The sign of the depreciation component is negative (positive) if the average value up to period t of the economic depreciation rate δ^* is higher (lower) than the average value for the whole sample period of the statistical depreciation rate δ. In other words, a negative (positive) depreciation effect may be interpreted as the result of an over-depreciation (infra-depreciation) during the sample period. The sign of the investment component is positive (negative) if the average value up to period t of the economic investment rate i^* is higher (lower) than the average value for the entire sample period of the statistical investment rate i. In other words, a positive (negative) investment effect would be the result of an over-investment (infra-investment) during the period under study. In any case, a given absolute value of the adaptability index may be associated with any of the four feasible combinations of signs.

Finally, we can also adapt the *index of resistance* (11) to the discrete framework in the following way

$$RID_t = Variance\ \left\{\sum_{t_0}^{t}\left(\gamma_{K_\tau^*} - \bar{\gamma}_K\right)\right\} =$$

$$= \frac{1}{(t-t_0)}\sum_{t_0}^{t}\left(\sum_{t_0}^{s}\left(\gamma_{K_\tau^*} - \bar{\gamma}_K\right) - \frac{1}{(r-t_0)}\sum_{t_0}^{r}\left(\sum_{t_0}^{s}\left(\gamma_{K_\tau^*} - \bar{\gamma}_K\right)\right)\right)^2. \tag{21}$$

[8]For a given T, the new term $\tilde{\imath}_\tau$ is variable because of the variability of δ_τ. The latter is related to the statistical measures of depreciation and capital associated with the Perpetual Inventory Method. The variability of the statistical depreciation rate along the balanced growth path only reflects the changes in capital composition. In the case of a constant capital composition, we would get $A\tilde{I}D_t^d \equiv AID_t = AID_t^d = \frac{1}{(1+n)}\frac{1}{(t-t_0)}\sum_{t_0}^{t}\left(\frac{1}{T}\sum_{s=1}^{T}\delta_s - \delta_\tau^*\right) + \frac{1}{(1+n)}\frac{1}{(t-t_0)}\sum_{t_0}^{t}\left(i_\tau^* - \frac{1}{T}\sum_{s=1}^{T} i_s\right)$.

Once again, as in the continuous case, the closer the value of RID_t is to zero, the greater the degree of resistance to shocks shown by economic systems. In other words, lower variance implies more resistance.

5 Resilience results for US and Spain

Next, we provide in the following table the main results for the US and Spanish economies. The results we show are the values of the different indexes for the entire samples: 1960-2011 for US and 1964-2011 for Spain.

Resilience Indexes: Comparative Results.

Country	**Adaptability** Index (AI)	Depreciation Effect	Investment Effect	Country	**Resistance** Index (RI)
US	+0.00004	-0.00072	+0.00076	SPAIN	+0.01145
SPAIN	-0.00071	-0.00147	+0.00076	US	+0.01223

Source: Own elaboration and official statistics. Escribá et al. (2018, 2019).

First, we can see that the US economy has shown a better adaptability to shocks than the Spanish economy. The value of the US index of adaptability is significantly lower than the absolute value of the Spanish index. In fact it is practically zero, which implies an almost complete adaptation to the shocks experienced throughout the full sample period. Moreover, the number of times that the short-run series for capital stock cuts the long-run series, does not play any role in the previous comparative result, because the frequency n is 3 for both Spain and the United States. Second, and at variance with the previous, the Spanish economy shows a lower value of the resistance index. The difference is not too high but it is enough to conclude that, for the entire sample period, the US economy has been less resistant to its shocks than the Spanish economy to its own. Then, putting the results of the two indexes together and comparing the two economies, we observe that it is not possible to reach a definite conclusion regarding resilience as a whole. There is not a clear dominance of one economy over the other simultaneously in the two attributes of resilience. While one dominates in resistance, the other dominates in adaptability.

Because of the full sample computation of the indexes in the previous table, a simplification of (20) when $t - t_0 = T$ may help to interpret the results under the columns corresponding to the depreciation and investment effects,

$$AID_T = \left(\frac{1}{1+n}\right)\left(\left(\frac{1}{T}\sum_{s=1}^{T}\gamma_{K_s^*}\right) - \bar{\gamma}_K\right)$$

$$= \left(\frac{1}{1+n}\right)\left(\left(\frac{1}{T}\sum_{s=1}^{T}\delta_s - \frac{1}{T}\sum_{s=1}^{T}\delta_s^*\right) + \left(\frac{1}{T}\sum_{s=1}^{T}i_s^* - \frac{1}{T}\sum_{s=1}^{T}i_s\right)\right). \qquad (22)$$

The adaptability index is then disaggregated into the depreciation and investment components. Abstracting from the correction term that involves the frequency n, the depreciation effect in equation (22) mainly measures the difference between the sample average of the long-run or statistical depreciation rate and the sample average of the short-run or economic depreciation rate. Similarly, the investment effect in the above equation mainly measures the difference between the sample average of the short-run or economic investment rate and the sample average of the long-run or statistical investment rate. Consequently, a negative (positive) depreciation component of the adaptability index is representative of an over-depreciation (infra-depreciation), while a positive (negative) investment component is representative of an over-investment (infra-investment). It is apparent from the table that, in average, during the last fifty years there has been over-depreciation and over-investment in both the US and the Spanish economies. The adaptation process in both economies after their corresponding shocks, seems to have been made through transitional over-efforts in the destruction of old capital and the acquisition of new equipment. However, one important feature of this process that arises from the figures shown in the table is that investment behavior in the two countries has been, in average, very similar (the investment component of the adaptability index takes the same numerical value). Consequently, the different ability to adapt in Spain and US is due exclusively to the different behavior of depreciation in these countries. For the entire period, in average, the endogenously determined economic deterioration and obsolescence has been lower in US than in Spain.

6 Conclusions

In this paper we address the concept of economic resilience and focus on the definition that emerges from engineering and physics. This is the most appropriate for the description of economic systems because it lies in the concepts of transitional and balanced growth paths. We measure resilience, which encompasses the properties of adaptability and resistance, by comparing the short-run with the long-run evolution of physical capital stock. This is at odds with the standard empirical literature that focuses on employment and labor market performance. We assume that the short-run trajectory is subject to all kinds of impacts but the long-run trajectory represents the evolution once the shocks have been completely absorbed. Our indexes of adaptability and resistance capture the extent to which the economy stays close to its potential or moves away. An economy that is better (worse) adapted and more (less) resistant may be classified as being more (less) resilient. However, it is not always possible to establish a clear and simultaneous relationship of dominance in terms of adaptability and resistance. Beyond this, we also propose a measure that decomposes the ability to absorb shocks in two terms that depend on depreciation and investment rates respectively. That is, we shed light on whether the adaptation has been based mainly on the destruction of the old capital or the acquisition of new equipment.

A case study concerning two different geographic areas, the US and the Spanish economies, is implemented to check the scope of our adaptability and resistance indexes in measuring economic resilience. Our quantitative measures are computed for the full sample period and provide a static global characterization of these economies. We find that the US economy shows a better result than the Spanish economy as regards the ability to adapt to shocks, but it shows a worse result regarding the capacity to resist and avoid the consequences of impacts. However, the lack of a unidirectional dominance relationship involving both attributes prevents us from answering the question of which of the two economies is more resilient. Our results also show that the higher adaptability of the US economy is based on a lower over-depreciation. This means that, in average, economic deterioration and obsolescence have played a more important role in Spain than in US.

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