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Carmen Pagliari¹, Nicola Mattoscio², Iacopo Odoardi³, Donatella Furia⁴

INSTABILITY AND INTRINSIC DISORDER IN
UNEMPLOYMENT DYNAMICS: A NONLINEAR REVISION OF
OKUN'S LAW

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Abstract

We test the significance of nonlinearity in unemployment dynamics by determining the analytical conditions for the existence of stable steady states, bifurcations and deterministic chaos, to investigate the intrinsic origin of irregularity in unemployment fluctuations. Our model, based on Okun's Law, permits deducing the role of labor market flexibility and labor productivity in the control of unemployment and provides policy suggestions. We empirically prove that uncontrollability of unemployment is sufficiently distant in most advanced economies. Nevertheless, using numerical experiments, we determine that there are countries in which unemployment evolves towards numerical disorder.

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KEYWORDS: OKUN'S LAW; NONLINEAR DYNAMICS; LOGISTIC MAP; UNEMPLOYMENT

1. Introduction

In economic studies, the relation between economic growth and

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unemployment is fundamental for suggesting policy measures to achieve macroeconomic objectives (Mankiw 2012; Romer 2012). This relation has been empirically tested and studied for many years, and a deeper knowledge of the involved dynamics should be useful for providing theoretically and empirically based forecasts. A well-known relationship that involves the GDP and the unemployment level was determined by Arthur Melvin Okun (1962), who observed an empirical regularity in the relationship between these variables in the US. The Law continues to be a reference point for scholars, since This regularity was proven to be a robust result in time (Blinder 1997) as, e.g., in the contribution of Valadkhani and Smyth (2015), who verified that the relationship was persistent in the United States since the Second World War, although weaker during the recession of the 1980s. For this reason, several studies (Economou and Psarianos 2016; Zanin 2016; Ibragimov and Ibragimov 2017; Guisinger et al. 2018) focused on interesting revisions of Okun's Law also in the post-crisis period.

Our aim is to study an analytical revision of Okun's Law on the basis of nonlinear dynamics, highlighting microeconomic interconnections and fundamental macroeconomic effects. and, as far as we know, few researches exist on the application of this method (see Section 3). We propose a theoretical model that is useful for investigating the endogenous conditions that generate stable steady states, bifurcations and deterministic chaos in unemployment dynamics and apply it to the G7 countries, deducing forecasts for the risk of chaos in two of these countries, the dynamics of which reveal opposite extreme characteristics. We examine possible economic interpretations of the coefficients of our model and the significance of the resulting forecasts. In particular, the coefficients we consider are based on some aspects of the theoretical interdependence between unemployment and GDP that are intrinsic to the system, and therefore they are suitable for an economic interpretation that is different from the explanation usually provided for an econometric coefficient. The nonlinear dynamic approach used for the study of deterministic chaos can appropriately contribute to this research field.

Our study is based on Okun's Law that is a quantitative expression of a persistent phenomenon (see Section 2). We analyze whether the dynamics of the unemployment rate may be characterized by chaos, i.e., being equivalent to disorder and uncontrollability. In our analysis we consider the widely used relation between the growth rate gap and the unemployment rate by formulating several hypotheses about the dynamics of the considered variables and using the logistic map. For the first application of the results of

our theoretical model, we focus on the G7 countries (as in Pierdzioch et al. 2011) in the period 1981-2017; in the second application of our model, we consider the data in the preceding eighteen years to analyze forecasts of the ranges of variability of the unemployment rate and compare the values to which the unemployment level should tend. The considered time periods include the recent Great Recession; hence, we show that the model can be used even in the case of a severe negative conjuncture. We expect at least the major economies to show a stronger presence of the Okun's relationship and greater socioeconomic stability. This should involve both avoiding chaos and showing similar levels of unemployment rates to which the economies could trend for the two periods analyzed.

For our research objective, we suggest that the level of complexity of a dynamic system can be analyzed by applying the methods of the mathematics of chaos. The applications of the logistic map that is characterized by nonlinearity and a unimodal representation are particularly useful in this framework. This map is suitable for a simple mathematical expression of the dynamics of a complex system, especially in the circumstances deriving from the presence of dual effects of a single cause that are connected by a chain reaction and responsible for nonlinearity (Rosser Jr. 2000; Strogatz 2014).

The introduction of the paper clarifies our specific research objectives. In Section 2, we discuss some aspects of the Okun's Law with a brief literature review that serves as the basis of our work, in reference to our research objectives. In Section 3, the model is presented, and the hypotheses of our analysis are described to deduce the fundamental nonlinear dynamic equation of the model that can be interpreted as an extension of Okun's Law. In Section 4, the discussion of the numerical consequences of steady states, bifurcations, cycles and chaos in relation to the alternative values of the parameters that characterize the nonlinear dynamics of unemployment is visualized by simple graphical representations. Evidence from the application of our model is highlighted to investigate if chaos is indeed significant in unemployment dynamics; in particular, we prove that the circumstances of deterministic chaos in unemployment dynamics are sufficiently distant in most of the advanced economies. In Section 5, policy suggestions are proposed.

2. Some aspects of Okun's Law

One of the reasons to keep attention to the contribution of A. M. Okun's Law in the 21st century is the analysis and comparison of different values of

its coefficient for the forecast and the systemic information that it can provide. We know that this coefficient varies according to the considered variables (e.g., note the difference between the use of the gross domestic income and the GDP in Nalewaik 2010), the analytic technique (Zanin and Marra 2012; Ibragimov and Ibragimov 2017) or the focus of the investigations (see the sectoral coefficients in Basu and Foley 2013; and see Okun's coefficients by age and gender in Zanin 2016). In the economic literature, alternative points of view exist on the consistency and adequacy of forecasts and policy implications derived from models based on Okun's Law. This empirical law is not always verifiable (it has scarce significance for Durech et al. 2014), and its characteristic coefficient changes for each examined context (e.g., the law is observed to hold in the G7 countries, but its coefficient varies according to Moosa 1997). In some cases, the significance of the relationship has been criticized (Meyer and Tasci 2012) in terms of the capacity of explaining economic recoveries (as in Owyang and Sekhposyan 2012) for what happened in the "jobless recoveries" after the last three recessions (see the role of labor force participation and productivity in Gordon 2010), while the law has been confirmed in the same context by other scholars (see Ball et al. 2013). Furthermore, there are studies that prove the validity of Okun's assumption in both the short run and the long run (Huang and Yeh 2013) as well as the high quality of the related forecasts (Ball et al. 2015). However, forecasts are subject to criticism because they are at risk of excessive change in value whenever there is the inevitable revision of the original macroeconomic data (Guisinger and Sinclair 2015). Finally, other criticism concerns the fact that several factors affect the determination of the output gap (see Prachowny 1993).

An important aspect to be considered in studies and tests of the aforementioned relationship is its validity during crisis and recessionary periods. In fact, it is reasonable to wonder if Okun's Law was still valid during the economic recession that followed the international financial crisis in many Western countries. Some scholars have considered a breakdown of the relation after the crisis (IMF 2010; Owyang and Sekhposyan 2012) or past crises (Daly and Hobijn 2010). According to Daly et al. (2014), the supposed breakdown of the relationship in the years of the crisis in the US is caused not only by the quality of real-time data compared to the revised values but also by the lag in the adjustment of employment levels. According to Elsby et al. (2010), the relationship is confirmed in the US at least until early 2009, when the increase in unemployment was combined with an economic recovery influenced,

according to the authors, by a contemporaneous strong increase in average productivity, as had occurred during the jobless recoveries that followed the previous two recessions in this country.

In fact, after an economic crisis, job growth could be lower than that expected from the Law (Gordon 2010). In Cazes et al. (2013), tests confirmed Okun's Law during the years of the 2007 financial crisis and that the variations of the relationship were due to the employment protection legislation of each country. For example, the presence of trade unions and collective bargaining makes Okun's relation weaker in many countries (see Izyumov and Vahaly 2002 for analysis of the relevant changes observed in formerly planned economies). Effects on unemployment are different and related to labor market protection expenditure in a relativity homogenous group of countries, as in Europe (Economou and Psarianos 2016). Labor market legislation causes large differences in the macroeconomic dynamics, as demonstrated, among others, by Sögner and Stiassny (2002) and Sarkar (2013).

Other studies (Palley 1993; Virén 2001; Silvapulle et al. 2004) have highlighted an asymmetry in Okun's Law: positive turns in the economic cycle have smaller effects on unemployment than do negative turns. As a result of the above findings, we expect to observe differences among the analyzed countries of the G7 group as a consequence of institutional and structural features. We know that recent applications of Okun's Law have confirmed the original empirical regularities for the US and Canada, highlighting the statistical significance of the same law being weaker in Europe and Japan (see, for an analysis of the G7 countries, Moosa 1997).

Policy suggestions can be proposed consistently with Okun's Law (Blinder 1997), which can be used to make valid forecasts (Mitchell and Pearce 2010). In this regard, there are studies suggesting that economists' forecasts for several advanced economies reflect Okun's Law (Pierdzioch et al. 2011 for the G7 countries and Pierdzioch et al. 2012 for the Eurozone). The contribution of Ball et al. (2015) also proves that forecasts based on the relation between the GDP and the unemployment rate are consistent with Okun's relationship, at least for advanced economies.

3. Unemployment's nonlinear dynamics

In view of our analysis, deterministic chaos is relevant to the study of unemployment dynamics. We observe that fluctuations in unemployment as well as in inflation and in many other macroeconomic variables are often

characterized by irregularity. The numerical disorder in the time series of these variables may be due to exogenous or endogenous causes, and the simple observation of time series may be insufficient for the investigation of the nature of these causes. The exogenous origin of irregular fluctuations is usually ascribed to stochastic events that affect the time evolution of the considered variables, while the endogenous origin can be explored in the possible presence of deterministic chaos.

The deterministic approach to economic dynamics is useful for testing the presence of potential endogenous chaos and for testing the characteristics of the future time paths in relation to the initial conditions, that determine the evolution of the economic system. If a model of deterministic dynamics is available, then it can simplify the analysis of the future time-paths of the economic variables over a large number of periods, emphasizing the dimensions of irregularity and unpredictability that are incorporated in the initial and/or actual conditions on which the future of the economic system is endogenously founded.

The significance of deterministic chaos in relation to the endogenous origin of business cycle irregularity has been proven by many studies since the 1980s (see Day 1982 and 1983; Goodwin 1990; Grandmont 1985). Therefore, the effectiveness of the deterministic approach should be examined also in relation to unemployment dynamics because of the strict interdependence between unemployment and business cycles.

A deterministic approach has been used for revising the Phillips curve (see Soliman 1996). Recently, the presence of deterministic chaos has been studied in relation to the dynamics of the trade-off between inflation rate and unemployment rate (Zhang 2006; Flaschel and Proaño 2014); however, very few studies investigated deterministic chaos in the dynamics of the unemployment rate based on Okun's approach (Jablanović 2011 and 2014).

The dynamic model that founds the analysis contained in this paper is based on five hypotheses that involve the growth rate gap (between the real output and its potential level) and the unemployment rate. The real output is the real GDP, and its potential value derives from IMF evaluations⁵. These dynamical assumptions, referred to as H1 ÷ H5, lead to a generalized nonlinear version of Okun's Law that will be explained in the following part of this Section.

A traditional form of Okun's Law can be expressed as follows (Dornbush

⁵ These values are calculated using the "Output gap in percentage of potential GDP" measure and the real GDP of the same year (source: IMF data).

and Fisher 1985, p. 483): $u_{t+1} = u_t - \gamma(g_{t+1} - g_{t+1}^e)$. In this form, Okun's Law states that the unemployment rate u declines by γ percentage points for every 1 percentage point of annual real output growth g above its potential level. On the other hand, the same law establishes that if output growth were 1% below its potential level, unemployment would rise by γ percentage points. In the formula, u_t is the unemployment rate at time t , while g_{t+1} and g_{t+1}^e are, respectively, the growth rate of real output at time $(t + 1)$ and the growth rate of the potential output at the same time, and γ is a real positive number (a parameter).

As the basis of our model, we assume the following five hypotheses (see Pagliari and Mattoscio 2019 for a general formalization of this model and its graphical representation):

H1 - There exists a linear relation between the growth rate gap at time $(t + 1)$ and the contemporaneous (i.e. in the same time) unemployment rate. The relation can be written as follows:

$$|g_{t+1} - g_{t+1}^e| = \rho u_{t+1} \quad (\rho > 0) \quad (1)$$

H2 - The growth rate gap is a function of the unemployment rate of the previous time:

$$|g_{t+1} - g_{t+1}^e| = f(u_t) \quad (2)$$

H3 - Function $f(u_t)$ is composed of two additive components that express two effects connected by a chain reaction and defined in the following hypotheses H4 and H5:

$$f(u_t) = D(u_t) + I(u_t) \quad (3)$$

H4 - Component $D(u_t)$ expresses a direct linear effect on the growth rate gap of time $(t + 1)$ due to the unemployment rate of time t :

$$D(u_t) = \alpha_D u_t \quad (\alpha_D \neq 0) \quad (4)$$

H5 - Component $I(u_t)$ expresses an indirect nonlinear (quadratic) effect on the growth rate gap of time $(t + 1)$ indirectly arising from the effect of the unemployment rate of time t on the contemporaneous aggregate demand:

$$I(u_t) = \alpha_I u_t^2 \quad (\alpha_I \neq 0) \quad (5)$$

Hypotheses H2, H3, H4, and H5, considered simultaneously, lead to the following dynamic relation:

$$|g_{t+1} - g_{t+1}^e| = \alpha_D u_t + \alpha_I u_t^2 \quad (6)$$

It is most significant to hypothesize a quadratic dependence of the absolute value of the real output growth gap $(g_{t+1} - g_{t+1}^e)$ on the unemployment rate u_t of the previous time. This statement is supported by some contributions in the economic literature. In fact, the nonlinearity of Okun's relationship has

been extensively tested in theoretical and applied studies (see Cuaresma 2003); additionally, other studies prove nonlinearity in unemployment and in labor markets both by theoretical (see Dufourt et al. 2008) and by empirical (see Panagiotidis and Pelloni 2007) approaches. Moreover, the observation of real data often shows a nonlinear relation between the GDP growth rate gap and the unemployment rate of the previous year, according to hypothesis H56.

In relation to hypotheses H4 and H5, we refer to a double effect of the unemployment rate on the growth rate gap of the real output. There is a direct effect induced on the level of the output growth rate gap by the direct technological link between the quantity of production and the labor factor. Moreover, there is an indirect effect on the level of the gap through the aggregate demand; this latter effect is influenced by the individual disposable income that originates from the level of production dependent on the level of the unemployment rate. These microeconomic and macroeconomic effects are the basis of nonlinearity in our theoretical model that is proposed for testing the presence of endogenous and intrinsic irregularity in unemployment dynamics.

Considering equalities (1) and (6), it is possible to obtain the following dynamic equation of the time path of the unemployment rate:

$$u_{t+1} = \lambda u_t + \Lambda u_t^2 \quad (7)$$

$$\text{where } \lambda = (\alpha_D/\rho) \text{ and } \Lambda = (\alpha_I/\rho) \quad (8)$$

If we use a suitable linear transformation of variable u_t in (7), we can write this equation in an equivalent way that leads to the corresponding “logistic map” (May 1976).

$$\text{The transformation is } u_t = -(\lambda/\Lambda)U_t \quad (9)$$

$$\text{The logistic map is } U_{t+1} = \lambda U_t(1 - U_t) \quad (10)$$

The coefficient λ is the characteristic parameter of the map itself, and equation (10) is the equation of the time path of the supporting variable U_t .

4. Graphical representations and evidence from the applications of the model

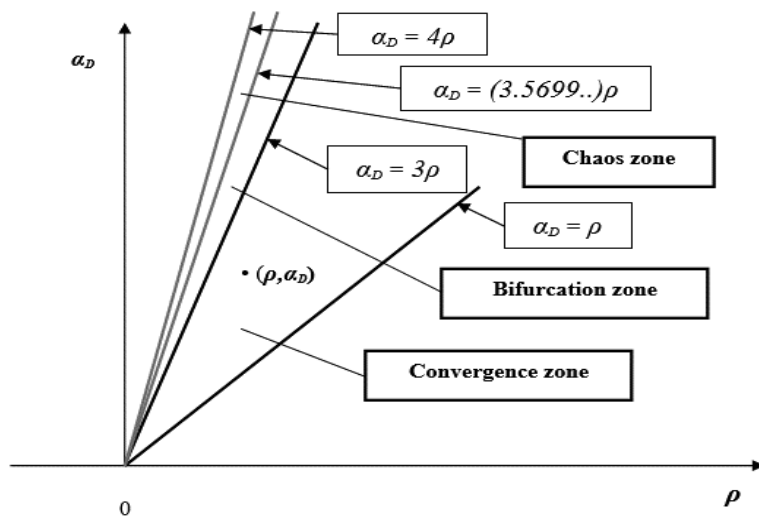
The analysis of the possible time paths of variable U_t (and consequently of the unemployment rate u_t) in relation to the variability of the characteristic parameter λ leads to the conditions for the existence of steady states,

⁶ In the Appendix, we analytically develop a theoretical proof of dependence of the GDP growth rate gap on the square of u_t .

bifurcations, and periodic cycles and to the values of the same parameter related to the onset of deterministic chaos.

The numerical and analytical consequences of the variability of parameters ρ and α_D are visualized in Figure 1.

Figure 1. Sets of pairs (ρ, α_D) .



The four half-lines in Figure 1 correspond to the cases related to the following equalities: $\alpha_D = \rho$ (half-line a); $\alpha_D = 3\rho$ (half-line b); $\alpha_D = (3.5699 \dots)\rho$ (half-line c); $\alpha_D = 4\rho$ (half-line d).

These half-lines delimit three regions - in the first quarter - named “Convergence zone”, “Bifurcation zone”, and “Chaos zone”.

If (ρ, α_D) belongs to the open region named “Convergence zone”, then there is a potential convergence to the stable steady state $u_2^* = (\rho - \alpha_D)/\alpha_I$, which is nontrivial.

If (ρ, α_D) belongs to the open region named “Bifurcation zone”, then there are bifurcations and cycles characterized by increasing periodicity if ρ increases.

If (ρ, α_D) belongs to the open region named “Chaos zone”, then there is deterministic chaos.

If (ρ, α_D) belongs to half-line b, then there is the first bifurcation; if (ρ, α_D) belongs to half-line c, then there is the onset of deterministic chaos, which also

persists if (ρ, α_D) belongs to half-line d.

For interesting economic interpretations and possible applications of these theoretical results, it is useful to observe that the values of parameters (or coefficients) ρ and α_D are influenced by important microeconomic aspects. The former expresses the ratio between the absolute value of the GDP growth rate gap and the contemporaneous unemployment rate, while the latter is the coefficient of the linear component in the quadratic function that expresses the relation between the GDP growth rate gap at time $(t + 1)$ and the unemployment rate at time t . The former can be related to labor productivity, and the latter can be considered an indicator of rigidity of the labor market.

After analyzing our theoretical nonlinear model and discussing the stability of its dynamic solutions, we propose some applications to contemporary advanced countries to study the levels of complexity and of intrinsic disorder that characterize their unemployment dynamics. Moreover, in this paper we will use the results of these applications to express some forecasts of the deterministic nature of unemployment dynamics in those countries, the evolutions of which will look interesting.

4.1 Results for G7 countries: 1981-2017

We have applied the above analysis using data from the October 2018 IMF World Economic Outlook database for the unemployment rates, the values of GDP at constant prices and the output gaps of the considered countries (Canada, France, Germany, Italy, Japan, the United Kingdom and the United States) for the period of 1981-2017. The absolute value of the gap ($|g - g^e|$) for each country is calculated using the GDP values and their gaps expressed as percentages of potential GDP. Moreover, using the time series of this gap and of the unemployment rate u , we have determined, for each country, the values ρ , α_D and α_I as the coefficients of hypotheses H1, H2 and H5, respectively, using best-fit functions. The calculation of the values, for each country, of the characteristic parameter of the logistic map λ is simply based on the first of formulas (8). To calculate the coefficient in equation (1), we have estimated a first-degree interpolating function for the values of u_t and $|g_{t+1} - g_{t+1}^e|$, as suggested by the model, without a constant term. For the coefficients in (6), the value of u_t is considered in relation to $|g_{t+1} - g_{t+1}^e|$ by using a second-degree interpolating function, without a constant term.

⁷ In our estimates, the year t in equations (1) and (6) is 1981.

In our numerical experiments, for the application of the logistic map we assume that the initial time ($t = 0$) coincides with the year 1981. It is possible to obtain the initial values of the supporting variable U_t . We consider transformation (9) in the initial time:

$$U_0 = -(\Lambda/\lambda)u_0 = -(\alpha_I/\alpha_D)u_0 \quad (11)$$

Aiming to determine the value of the unemployment rate to which each system tends or the range and its time series representation, it is necessary to calculate the values of u after determining the values of the supporting variable U obtained by the logistic map. The transformation is expressed by the following formula:

$$u_t = -(\lambda/\Lambda)U_t = -(\alpha_D/\alpha_I)U_t$$

In Table 1, we show the results of our model applied to the G7 countries for the period 1981-2017. The model parameters are followed by the value of u^* that represents the percentage (or the range) of the unemployment rate to which each system tends, given the parameters and the value of the unemployment rate in the initial year 1981.

Table 1. Values of the characteristic parameter of the logistic map for unemployment dynamics in the G7 group and the level of the trend of the unemployment rate (1981-2017).

Country	Coefficient α_D from function (6)	Coefficient ρ from function (1)	Coefficient $\lambda = (\alpha_D/\rho)$	u^* or fluctuation range
Canada	0.0029	0.0016	1.8125	6.50
France	0.0036	0.0009	4.0000	0.0002-12.00
Germany	0.0035	0.0015	2.3333	10.00
Italy	0.0039	0.0010	3.9000	1.24-12.68
Japan	0.0069	0.0033	2.0909	4.00
UK	0.0021	0.0012	1.7500	9.00
US	0.0027	0.0020	1.3500	7.00

Authors' analysis of the IMF data.

Note: the minimum and maximum values for France and Italy are obtained considering the first one thousand repetitions of the logistic map.

From the results of the application of our model (see Table 1), we deduce the following statement: the nonlinear dynamic of unemployment is sufficiently distant from the risk of onset of deterministic chaos that, however, is not to be excluded. In fact, in relation to G7 countries during the period 1981-2017, it is possible to observe that the values of the characteristic parameter $\lambda = (\alpha_D/\rho)$ mostly belong to the interval of real numbers (1,3), except for the chaotic circumstances of France and Italy.

Moreover, it is possible to observe from Table 1, consistent with the contribution of Moosa (1997) for the G7 countries, the difference between the values of coefficient λ of the US and Canada compared to values of European countries. This comparison can be related to different levels of flexibility of labor markets (see the finding of Lee 2000; Sögner and Stiassny 2002) and consequently to different levels of ability to adapt to the dynamics of the economic system, which is relatively stronger in Canada, the UK and the US. These results are consistent with the OECD indicator of Employment Protection Legislation "Protection of permanent workers against individual and collective dismissals". This indicator shows a value higher than 2 for all countries⁸ except Canada (1.51), the UK (1.59) and the US (1.17).

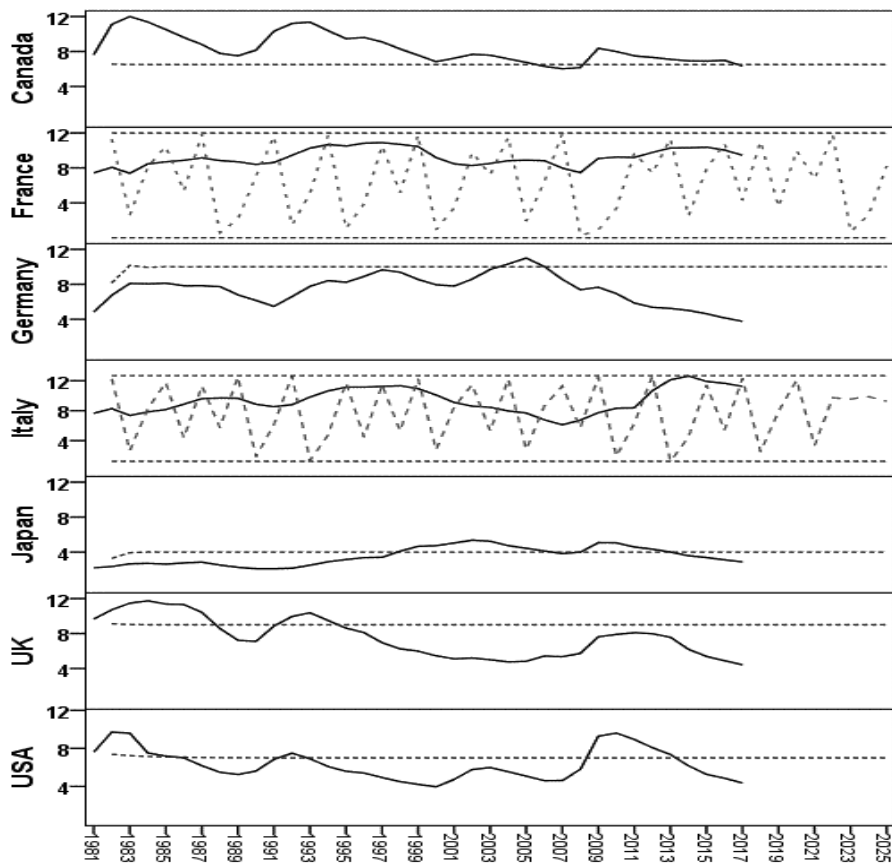
The results suggest that the considered advanced economies have several possible time paths of unemployment. In view of the economic literature, the unemployment rate dynamics is strongly linked to institutional and structural characteristics of each country. The greater adaptability of the labor market to short-term adjustments, e.g., in the US, has sustained a rapid economic recovery after the 2007 crisis and enabled the control of the employment dynamics. In contrast, the rigidity of labor legislation makes it difficult to adjust employment in different economic circumstances, e.g., in Italy, leading in turn to the risk of unpredictability and especially to high unemployment levels in periods of economic slowdown.

Applying transformation (9) to the results of this numerical experiment based on the logistic map, it is possible to forecast approximately - using the interval of the considered iterations - the ranges of variability of the unemployment rate in the seven countries until 2025. This type of forecast reflects only the intrinsic and deterministic dynamics of the system that originate from the systemic characteristics in the considered initial year, without taking into account random exogenous events and policy

⁸ France: 2.82; Germany: 2.84; Italy: 2.89; Japan: 2.09. The available OECD data are for 2013.

interventions. Figure 2 shows the graphs for the seven countries, representing the time series of the unemployment rate, the results from the logistic maps and some forecasts.

Figure 2. Unemployment rate (black lines, %), u^* (gray dotted lines) and ranges⁹ for the G7 countries (1981-2017).



Source: Authors' analysis of the IMF data

The 1981-2017 period that we have considered for applying the main results of our model in the G7 countries includes the international economic crisis of 2007. In Figure 2, we observe that the inclusion of the effects of the

⁹ For France and Italy, both the range of values (horizontal lines corresponding to minimum and maximum values based on one thousand repetitions) and the values of the logistic map are reported.

crisis in the analysis and the review of the obtained results support the possibility of applying the model to contexts with severe fluctuations. In view of these observations it is interesting to consider the G7 countries in the period of recent Great Recession (Section 4.2).

4.2 Preceding two decades and the Great Recession

In the following analysis, we apply the logistic map to the G7 countries considering the period 2000-2017. This period should contain sufficient observations to verify the Okun's relationship; at the same time, approximately half of the years are characterized by recessionary effects in many countries. We show forecasts in this case also to observe differences with respect to the previous analysis. We expect that the major economies experience fewer exogenous effects and therefore exhibit a more evident presence of Okun's Law. This should mean that at least the US, Japan and Germany (the world's 1st, 3rd and 4th economies, respectively, according to the GDP at current prices of 2017) have values of λ similar to that estimated in Section 4.1.

Table 2. Values of the characteristic parameter of the logistic map for unemployment dynamics in the G7 group and the level of the trend of the unemployment rate (2000-2017).

Country	Coefficient α_D from function (6)	Coefficient ρ from function (1)	Coefficient $\lambda = (\alpha_D/\rho)$	u^* or fluctuation range
Canada	0.0055	0.0015	3.6667	2.57-8.40
France	0.0081	0.0008	10.1250	-
Germany	0.0025	0.0018	1.3889	7.78
Italy	0.0046	0.0012	3.8333	2.35-14.69
Japan	0.0072	0.0030	2.4000	4.20
UK	0.0039	0.0014	2.7857	6.25
US	0.0046	0.0018	2.5556	7.00

Authors' analysis of the IMF data.

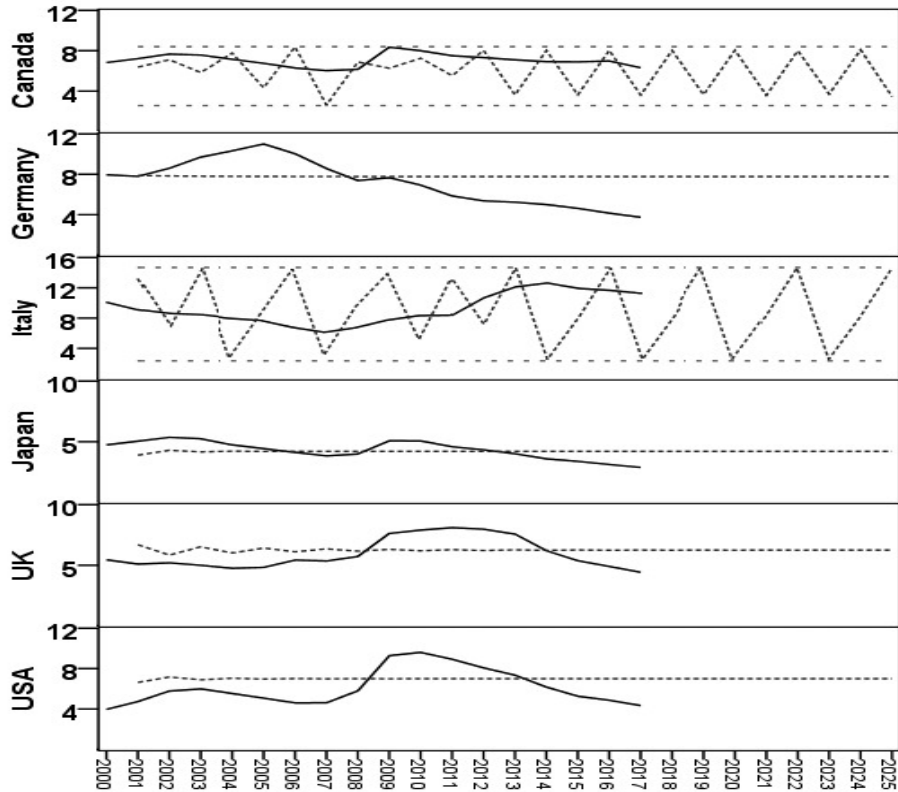
Note: the minimum and maximum values for Canada and Italy are obtained considering the first one thousand repetitions of the logistic map.

In Table 2, four countries out of seven are in the “Convergence zone”; Canada is in the “Chaos zone”, as is Italy (confirming the result for this country in Table 1), while the λ value of France exceeds the threshold value of 4 and does not allow making estimates for the period considered. We observe evident effects of the recent crisis in the values of λ and u^* . In Canada, a notable increase in λ is evident, but the value of the unemployment trend level previously estimated is within the range estimated for 2000-2017. The trend values of Germany and the UK have decreased despite the crisis, due to the rapid economic recovery, while the Italian range has widened both in amplitude and in the absolute values of the level of unemployment. Japan’s value of u^* increased by only 0.2%, and, as expected, the respective value of the largest global economy - the United States - remained unchanged, suggesting an unemployment level of 7%. These changes confirm that the dynamic of unemployment is characterized by complexity because it depends on the initial conditions, *i.e.*, on the initial year of the analysis. This observation leads us to be sure of the significance of nonlinearity in the search for a more fitting quantitative relation between the unemployment rate and the growth rate gap of the GDP.

In Figure 3, we show the time series, the results from the logistic map and the 2018-2025 forecast of the unemployment rate¹⁰.

¹⁰ The graph for France has been omitted because the model is inapplicable for $\lambda > 4$.

Figure 3. Unemployment rate (black lines, %), u^* (gray dotted lines) and ranges¹¹ for the G7 countries (2000-2017).



Source: Authors' analysis of the IMF data

A detailed examination of the crisis years shows that the most recent time series represented in Figure 3 are consistent with the results of the logistic map - values to which each system would tend and particularly their “predictability” - despite the trends varying by country. An increase in unemployment of up to 5 percentage points occurred between 2007 and 2009 in all countries except Germany. In the more resilient countries, an inversion of the trend emerged since 2010 (Canada, Germany, and Japan), 2011 (the US) and 2012 (the UK), while in Italy the first decrease in u occurred in 2015.

¹¹ For Canada and Italy, both the range of values (horizontal lines based on the minimum and maximum values based on one thousand repetitions) and the values of the logistic map are reported.

These observations are a strong motivation to revisit Okun's Law. Our results are consistent, for example, with the findings of Lee (2000) that shows that the relation is less robust in OECD developed countries, while Zanin and Marra (2012) prove that Okun's relationship has varied in the preceding decade and that it is spatially heterogeneous and time-varying in Europe. Furthermore, Malley and Molana (2008) investigate the implications of the different algebraic signs of the relation between output and unemployment due to rigidities or distortions, observing that only the data for Germany, among the G7 countries, support a monotonic relation.

5. Conclusions

The empirical evidence involved in Okun's Law is strongly confirmed by many studies, but the linearity of the relation is not universally true, and it is not very informative about deeper aspects of dynamics of unemployment in contemporary developed countries. In addition, recent studies suggest that in periods of crisis, the unemployment rate is considered an effective summary measure of the economic conditions (e.g., Daly *et al.* 2014).

In this paper, we test the significance of nonlinearity in unemployment dynamics using tools of the mathematics of chaos and simultaneously introducing a formalization of an indirect quadratic effect on the unemployment rate of the next period, deriving from a chain reaction conveyed by the aggregate demand, resulting from the primary effect on unemployment itself. It is well known that nonlinearity may imply chaos, fluctuations, instability and, under certain conditions, convergence to stable steady states. Of course, these results imply the possibility of adjusting policy interventions towards desirable employment targets. Our analysis shows that the complexity of the aggregate global system will determine all these dynamic aspects of unemployment's evolution over time.

Both the diverse countries in the G7 group and the recessionary years were useful for applying the model. The average annual variation of the pre-crisis decade shows a negative sign for all countries, while the countries that show a risk of chaos in the unemployment dynamics – Canada, France and Italy – are the only ones to have a positive variation of the post-crisis average annual unemployment rate (2008-2017)¹². All the other countries showed a rapid recovery towards pre-crisis values.

¹² The average increase is 0.03% in Canada, 0.15% in France, and 0.51% in Italy (obtained by analysis of the IMF data).

Of course, the local labor market institutions are the direct determinants of the differences in the effects on the involved variables, particularly unemployment, which is consistent with the economic literature (Stockhammer and Klar 2011) and with the interpretation of our results, as shown in the application of our model to the G7 countries. In our results, differences between European and North American countries indeed emerge, thus confirming that flexibility of the labor market, which is revealed to be at different levels in the two groups of countries, is an important determinant of unemployment dynamics.

However, numerical disorder in unemployment dynamics is possible. In fact, we observe the cases of France, Italy and partially Canada, in which unemployment dynamics evolve towards disorder and uncontrollability if the challenging period of the Great Recession is considered.

The analysis contained in this paper suggests the possibility of controlling unemployment dynamics by two coefficients (α_D and ρ), the ratio of which must not exceed a specific threshold value to avoid chaos. The former can be considered an indicator of rigidity of the labor market, while the latter can be related to labor productivity. Our study confirms that these two aspects are crucial for the control of unemployment dynamics and for the achievement of stable results (for the role of labor market flexibility, see the contributions of Guisinger *et al.* 2018 and of Oh 2018).

In the search of cases at risk for chaos, our analysis shows, e.g., that in Italy, the endogenous weakness in potential economic development generates instability and uncontrollability of unemployment, which is due both to the presence of a rigid labor legislation and to the inadequacy of labor productivity. Indeed, the characteristic parameter of the logistic map depends positively on the increase in the rigidity of the labor market and negatively on the increase in labor productivity. In Italy, as the labor market is relatively rigid and the labor productivity is under its potential level¹³, the parameter of the logistic map is higher than the threshold value, determining chaotic time paths of the unemployment rate. This disorder in the dynamics of the unemployment rate is also related to the lack of economic recovery after the 2007 crisis in this country, which is evident from the considered time series data. The results of Italy confirm the very basis of Okun's intuition, which

¹³ In Italy, over 20 years of legislative actions to increase flexibility induced a block in labor productivity growth (Lucidi and Kleinknecht 2010).

highlights the role of an appropriate economic growth rate in solving the socioeconomic problems related to unemployment. Thus, the findings of our work sustain Okun's idea by adopting a nonlinear dynamic approach and complete it by criteria for the control of instability and economic disorder.

The bifurcations and chaos depend on the values of the characteristic parameter of the logistic map and, therefore, on the two coefficients that we have described above. From the microeconomic point of view, considering the dynamic hypotheses that introduce these coefficients, it is interesting to observe that the first of them embeds the effects of the behavior of households in relation to consumption spending and the effects of investment choices of firms. The second coefficient expresses the technological links that exist between the variables.

These observations allow us to assert that our contribution is a revision of Okun's Law that consists not only of the consideration of nonlinearity but also of a novel interpretation of the microeconomic causes of the relationship between unemployment variation and the GDP gap over time. Finally, we observe that ability of our analysis to forecast the ranges of variability of the unemployment rate is not due to the use of techniques belonging to expectation modeling or forecast modeling. Our model is based on theoretical dynamic relations (expressed by the hypotheses of Section 3) that involve intrinsic aspects of the system. These intrinsic aspects are embedded in the two coefficients (and their ratio) that we have used in our model. Our characterization of their macroeconomic and microeconomic interpretation provides new suggestions for a deeper revision of Okun's Law and for policy interventions.

Appendix

Analytical micro-founded macro model supporting the dependence of GDP growth rate gap on the square of u_t

Assume that output is produced according to the following production function:

$$Y_t = A_t [(1 - u_t)L_t]^\alpha K_t^\beta \quad (\alpha > 0, \beta > 0) \quad (1.A)$$

where A_t is the total productivity of factors, L_t is the labor force (measured by the total number of hours worked), u_t is the unemployment rate, and K_t is the aggregate stock of physical capital. If N is the total number of employees (constant over time) and l_t is the average number of hours worked per employee, then $L_t = l_t N$.

Equation (1.A) is equivalent to the following:

$$Y_t = \Phi_t (1 - u_t)^\alpha \quad (2.A)$$

where $\Phi_t = \Phi_t(A_t, l_t, K_t) = A_t l_t^\alpha K_t^\beta$.

We focus on business cycle fluctuations and assume a constant level of potential output (for simplicity, we assume it to be equal to zero). Furthermore, we neglect short-term variations in physical capital. In this case, variations in Φ_t reflect short-term variations in productivity A_t and short-term variations in the intensive margin of employment l_t . Suppose that we take the process $\{\Phi_t\}$ (*i.e.*, productivity and hours worked per employee) as a given. This assumption is only made for simplicity and can, of course, be weakened. However, the search-and-match framework uses this assumption.

Using $Y_t = (1 - u_t)^\alpha \Phi_t(A_t, l_t, K_t)$, we obtain

$$\ln Y_{t+1} = \alpha \ln(1 - u_{t+1}) + \ln \Phi_{t+1}(A_{t+1}, l_{t+1}, K_{t+1})$$

Using the approximation $\ln(1 - z) \approx -z$, we obtain

$$\ln Y_{t+1} \approx -\alpha u_{t+1} + \ln \Phi_{t+1}(A_{t+1}, l_{t+1}, K_{t+1}) \quad (3.A)$$

Taking the process $\{\Phi_t\}$ as a given, any macro model of the labor market will determine an equilibrium law of motion that can be generically expressed by the following map:

$$u_{t+1} = G(X_t, \Phi_{t+1}, \Phi_t), \quad (4.A)$$

where X_t is the relevant endogenous state variable. The definition of X depends on the model at hand; for our purpose, we let $X_t = u_t$ and thus, from (3.A) and (4.A), we obtain

$$\ln Y_{t+1} \approx \alpha G(u_t, \Phi_{t+1}, \Phi_t) + \ln \Phi_{t+1}(A_{t+1}, l_{t+1}, K_{t+1}).$$

If G is a map separable in u and Φ , it is possible to obtain

$$\ln Y_{t+1} \approx \alpha G_1(u_t) + \alpha G_2(\Phi_{t+1}) + \alpha G_3(\Phi_t) + \ln \Phi_{t+1}(A_{t+1}, l_{t+1}, K_{t+1}). \quad (5.A)$$

Under the standard hypotheses of derivability with respect to variable t , we can calculate the derivative D_t of both sides of equation (5.A) and obtain

$$D_t(\ln Y_{t+1}) \approx \alpha D_t[G_1(u_t)] + \alpha D_t[G_2(\Phi_{t+1})] + \alpha D_t[G_3(\Phi_t)] + D_t[\ln \Phi_{t+1}(A_{t+1}, l_{t+1}, K_{t+1})].$$

Moreover, as $D_t(\ln Y_{t+1})$ is equal to the growth rate at time $(t+1)$, and according to the variability of the relevant endogenous state variable only, we obtain $g_{t+1} = \alpha D_t[G_1(u_t)]$, which we transcribe as follows, using the definition $F(u_t) = D_t[G_1(u_t)]$:

$$g_{t+1} = \alpha F(u_t)$$

Using a linear-quadratic approximation of $F(u_t)$, we obtain

$$g_{t+1} = \alpha (\beta_1 u_t + \beta_2 u_t^2) = (\alpha\beta_1)u_t + (\alpha\beta_2)u_t^2 \quad (\beta_1 \neq 0, \beta_2 \neq 0).$$

Finally, with $\alpha_D = \alpha\beta_1$ and $\alpha_I = \alpha\beta_2$, we can write

$$g_{t+1} = \alpha_D u_t + \alpha_I u_t^2,$$

which matches equation (6) of this paper if $g_{t+1}^e = 0$.

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MEASURING THE STANDARD OF LIVING OF INFORMAL
WORKERS OF THE MANUFACTURING SECTOR IN UTTAR
PRADESH

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Abstract

In India, where more than 90% of workers are employed in the informal sector, contributing more than 50% of the country's GDP, the manufacturing sector alone contributes more than 18%. Still, informal workers in this manufacturing sector cannot live decent life due to the lack of financial, employment, and social security. Most of the informal workers are struggling for the necessities of life and trying to match their living standards to society. This study is an attempt to analyse the living standards of manufacturing informal workers in Uttar Pradesh to attract the attention of the government towards the living condition of workers. For that purpose, the Standard of Living Index (SLI) of 385 informal workers in the manufacturing sector has been developed. The scores have been allocated based on the value of land-holding, possession of material goods, possession of live stocks, and availability of basic amenities like housing facilities, electricity connection, sanitisation facility, and drinking water facilities. This study also analyses the impact of various supply-side factors on the standard of living using the Ordinary Least Square (OLS) method. While 38.2% of informal workers have been found in the low SLI category, 2.1% are in the high SLI category. Further, a significant and positive impact is found of caste, area of residence,

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gender, and no. of earning members in the family on the standard of living of workers.

JEL CODES: J46, J01, O17, L6

KEYWORDS: LIVING STANDARDS, INFORMAL WORKERS, MANUFACTURING SECTOR, INDEXING

1. Introduction

According to ILO's Labour Force Survey, 2020, India has a labor force of 501 million, out of which 360.57 million are working in the informal sector. Out of these 360.57 million, 10 million workers are engaged in only manufacturing activities. At the same time, they are the most productive sector, with a contribution of 30% to the Indian economy and a total contribution of more than 18% to GDP, followed by a contribution of 14% to the agriculture sector. Still, the informal workers of the manufacturing sector belong to a highly vulnerable group of society.

The basic premise of social development in industrialised nations is that indemnified work brings employment and security by offering financial protection and a road to a higher lifestyle for human children. The early social security model was a country with (almost) full employment and a level of remuneration in which the people might be able to meet the needs of their households (Lund, F. 2012). However, the reality is far different from the assumptions. Manufacturing informal workers work at very high risk to their physical and mental health, having no health security measures (Dhas et al., 2008). Still, they do not get fair wages, employment, or financial security. They struggle every day to provide for their family's basic needs. They struggle day and night to get basic amenities like shelter, food, clothing, higher education, Etc. Most of these workers do not get any compensation in case of an accident, no paid leave, no overtime compensation, and no higher rate of wages for night-shift (Vicente et al., 2016). Sometimes they had to face mental harassment and discrimination based on gender, caste, religion, and sometimes even based on their state of origin (Garg, 2012). Even though the government decides that the minimum wage is insufficient to fulfil workers' basic needs, they do not get the minimum wage (Rani et al., 2013). They also

had to put their children to work because the lack of financial security and savings led to child labour and violation of the right to education.

In India, 93% of the workforce works in the unorganised sector. The sector makes up over 50% of the GDP of the nation. However, since they lack employment, job security, and social protection, employees in the informal sector remain poor and vulnerable throughout their working and social lives. (Bora, 2014). Their living conditions are not any better than their working ones, notwithstanding how terrible their working conditions are. Most of the workers live in unfurnished Kachcha-houses with five-six people sharing a single room and having no privacy. There is no separate space for cooking food, and they must depend on clean drinking water from municipal arrangements or private handpumps of neighbours. Having no agricultural land or domestic cattle increases their financial vulnerability, which leads to depression, addiction to intoxication, and involvement in illegal activities like burglary, phishing, vishing, Etc.

The Indian economy has grown relatively faster during the last two decades, which is impossible without the contribution of informal sector workers. While an increase in GDP is anticipated to boost workers' productivity, accelerate income growth, and thus enhance working and standard of living. However, despite many labour welfare acts and policies made by the government, there has been no improvement in the living condition of workers. As most organisations do not comply with acts and policies, the government cannot improve workers' living conditions. Also, workers can only fight for their rights with an independent labour union.

While many researchers analysed informal workers' living conditions, very few specifically focused on the workers in the manufacturing sector, which is one of the highest contributing sectors to the Indian GDP. In light of this, the current study seeks to determine if informal workers in the manufacturing sector have profited from the country's phenomenal economic boom. The dream of inclusive growth will undoubtedly come true if their conditions improve. This article starts with an introduction, then divides into five sections: a second section that looks at previous research, a third section that describes the methodology, a fourth section that examines the living conditions of the workers, and a fifth section that examines the effects of different supply-side factors on their standard of living. In addition to providing a policy framework to enhance the living circumstances of informal sector workers employed in Uttar Pradesh's manufacturing sector, the research

intends to draw the attention of the state and central governments to the terrible living conditions of workers.

2. Review of Literature

This paper analysed the impact of various social-security schemes on informal workers (Pillai, 1996). The study found that the introduction of social security for casual workers in the informal sector in Kerala was somewhat incomparable. The study also showed that the Welfare Fund Scheme has brought about a drastic change in the standard of living of workers socially and economically. (Roy et al. 1999) tried to establish a relationship between the Standard of Living (SLI) and fertility of women (with at least ten years of marital duration) in four states of India, namely Kerala, Punjab, Maharashtra, and Uttar Pradesh. They took land holding, type of house, possession of material goods, and livestock as the standard of living Indicators.

Developed three SLI levels, Low SLI, Medium SLI, and High SLI, based on the sum of scores assigned to different indicators of SLI. They concluded that it is not always SLI, but many other social factors directly or indirectly impact the fertility decline. Out of four states, only Punjab showed the expected negative relationship between SLI and fertility change. (Be'Renger & Verdier-Chouchane, 2007) Sen's capacity method assessed life satisfaction by dividing it into two parts: quality of life (QL) and standard of living (SL). In contrast to the UNDP Human Development Index (HDI), this research tried to distinguish between resource availability and capability metrics. The study used two multidimensional measures, SL and QL, to assess the empirical findings from 170 nations. According to the study, SL and QL have greater diversity than HDI. These two metrics are more helpful in developing social and economic strategies to address structural under-development. (Mohapatra, 2012) a descriptive analysis of 500 female informal workers in Odisha found that many live lives full of compromises and necessities. They also found that low wages imply numerous other issues that impact female workers' living standards and nutrition. (Rao, 2015) With roughly 64% of all jobs coming from the informal sector, this sector is significant for Hyderabad's economy. He suggests a policy framework that includes health care facilities, old-age pension, maternity, accident benefits, micro-financing facilities, Etc. In light of the importance and lousy state of the informal sector. (Muthusamy and Ibrahim 2016) This review paper attempted to analyse informal employment in several economic sectors and found that the agriculture industry employs

more informal employees than other sectors. The ever-increasing urban and young population is obliged to adopt informal commerce as a means of survival due to rising unemployment and the formal economy's failure to produce jobs for them. (Antony et. al. 2017) The standard of living and human development depends on many variables. Demographics, health, nutrition, and socio-economic indicators play a significant role in determining living standards. Current indicators, such as HPI and HDI, do not consider income indicators to estimate the quality of life and ignore dietary and nutritional indicators. However, the proposed indicators are beneficial in estimating actual development and quality of life as they also incorporate income and income indicators.

3. Research Methodology

Data has been collected through the questionnaire on the basis multi-stage stratified sampling method. The state selected five cities (Barabanki, Ambedkar Nagar, Amethi, Sultanpur, and Ayodhya) as they belong to the Ayodhya magistracy and are also the central manufacturing units like NTPC, and Parle is situated here. Then, four manufacturing units and 20 workers from each unit were selected randomly. It is ensured that the respondent is the family's primary wage earner and that a family member in a formal or government job supports no household. Workers were selected from different households. A total of 400 workers were interviewed face-to-face from August 2021 to January 2021. 385 questionnaires were considered in this study after refining the received responses.

This study will examine the standard of living index of informal workers working in the manufacturing sector of Uttar Pradesh. The indicators of standard of living, e.g., Housing arrangement, Access to clean water, Sanitization facility, Etc. Furthermore, to develop the Standard of Living Index based on these indicators.

Secondly, the study seeks to investigate the worker's qualification, the current area of residence caste, and the number of persons employed other than the respondent on the standard of living using the Ordinary Least Square (OLS) method and the hypotheses proposed are: -

H1: There is a significant impact of worker's education level on the standard of living

H2: There is a significant impact of worker's current area of residence on the standard of living

H3: There is a significant impact of worker’s caste on the standard of living

H4: There is a significant impact of the number of persons employed other than the respondent on the standard of living

3.1. Indexing of Standard of Living

The critical question is, what will be the adequate measures to explore the actual living condition of a household? Researchers varyingly denoted economic condition either by the level of income or expenditure made by the household to acquire material goods for their comfort. However, the current income could be a better alternative for measuring a person's economic condition because it is possible that, while earning relatively well, a person may need adequate access to necessities because of the large number of dependents in the household. Since when parents decide about the family size, they have potential income in mind, not the current income. However, reliable information about the potential or expected income is impossible to collect through a survey (Easterlin et al., 1969). This study has decided to measure a labour household's economic condition through a Standard of Living Index (SLI). For that purpose, indexing is done, and weights are assigned to the possession of material goods like T.V., Radio, By-cycle, Two-wheeler, domestic livestock, ornaments, the value of the land they possess, and also the basic amenities like the type of house, drinking water facility, sanitation facility, Etc. (Roy et al. 1999).

Table 1. Scores assigned to the Standard of Living Index (SLI) variables

		Variables	Score
1.	Type of House	Pucca	= 2
		Semi-Pucca	= 1
		Kachcha	= 0
2.	No. of rooms in the house	Three or more than three	= 2
		Two	= 1
		One	= 0
3.	Separate room for every person	Yes	= 1
		No	= 0
4.	Separate kitchen in the house	Yes	= 1
		No	= 0
5.	Fuel for cooking	Electricity/LPG	= 2
		Kerosene	= 1
		Firewood	= 0

Table 1. Scores assigned to the Standard of Living Index (SLI) variables (continued)

Variables		Score
6.	BPL card holder	Yes = 1
		No = 0
7.	Sanitization Facility	Separate = 2
		Common = 1
		Open-field = 0
8.	Electricity connection	Yes = 1
		No = 0
9.	Source of drinking water	Submersible/private handpump = 2
		Municipal Supply/public handpump = 1
		Other = 0
10.	Own Tube-well	Yes = 3
		No = 0
11.	Livestock ownership	Buffalo = 2
		Cow = 2
		Goat = 1
12.	Ownership of goods	Fan = 1
		Television (Black & white) = 2
		Television (Color) = 3
		Radio = 1
		Mixer-grinder = 2
		Refrigerator = 3
		Washing Machine = 3
		Mobile Phone = 2
		Computer = 3
		Bicycle = 1
		Two-Wheeler = 3
		Car = 4
		Tractor = 4
		Chair = 2
		Table = 2
Almirah = 2		
DVD/VCD player = 3		
Iron = 2		
Sewing machine = 2		
Gas Stove = 2		
Gas Stove = 2		

Table 1. Scores assigned to the Standard of Living Index (SLI) variables (continued)

Variables		Score	
13.	Gold/Silver ornaments	Value \geq ₹ 1,00,000	= 3
		Value \geq ₹ 50,000	= 2
		Value $<$ ₹ 50,000	= 1
		No ornament	= 0
14.	Land Holding	Value \geq ₹ 10,00,000	= 3
		Value \geq ₹ 5,00,000	= 2
		Value $<$ ₹ 5,00,000	= 1
		No Land	= 0
Standard of Living Index (SLI)		Score Range	0 to 79
Categories of SLI		Range	
Low SLI		0 to 15	
Medium SLI		15 to 30	
High SLI		31 and above	

Source: Based on the indicators taken by (Roy et al. 1999)

$$\text{Total SLI score} = \sum_{i=1}^{36} \text{SLI}_i + \text{SLI}_{11} + \text{SLI}_{12} + \text{SLI}_{13} + \dots + \text{SLI}_{36}$$

Where,

SLI1: Type of House, SLI2: No. of rooms in the house, SLI3: Separate room for every person, SLI4: Separate kitchen in the house, SLI5: Fuel for cooking, SLI6: BPL card holder, SLI7: Sanitization Facility, SLI8: Electricity connection, SLI9: Source of drinking water, SLI9: Own Tube-well, SLI10: Buffalo, SLI11: Cow, SLI12: Goat, SLI13: Fan, SLI14: Television (Black & white), SLI15: Television (Color), SLI16: Radio, SLI17: Mixer-grinder, SLI18: Refrigerator, SLI19: Washing Machine, SLI20: Washing-Machine, SLI21: Mobile phone, SLI22: Computer, SLI23: Bicycle, SLI24: Two-wheeler, SLI25: Car, SLI26: Tractor, SLI27: Chair, SLI28: Table, SLI29: Almirah, SLI30: DVD/VCD Player, SLI31: Electric Iron, SLI32: Sewing-machine, SLI33: Gas stove, SLI34: Gas cylinder, SLI35: Gold/Silver Ornaments, SLI36: value of land holding

4. Results & Discussion

Table 2. Total Standard of Living Index (SLI) Score of the workers.

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Low SLI	147	38.2	38.2	38.2
Medium SLI	230	59.7	59.7	97.9
High SLI	8	2.1	2.1	100.0
Total	385	100.0	100.0	

In table 2 above, SLI scores of individual workers are added. Out of 385 workers, 147 workers (38.2%) fall in the category of low SLI, 230 workers (59.7%) are in the category of Medium SLI, and the remaining only eight workers (2.1%) come under the category of High SLI. It is observed that more than 97% of informal workers either lack basic amenities or struggle to live a decent life. Only 2.1% of informal workers in High SLI may be because of a paternal background.

Table 3. Total SLI * Gender Crosstabulation

		Gender		Total	
		FEMALE	MALE		
Total SLI	Low SLI	Count	8	139	147
		% within Gender	25.8%	39.3%	38.2%
	Medium SLI	Count	22	208	230
		% within Gender	71.0%	58.8%	59.7%
	High SLI	Count	1	7	8
		% within Gender	3.2%	2.0%	2.1%
Total	Count	31	354	385	
	% within Gender	100.0%	100.0%	100.0%	

In table 3 above, out of 385 respondents, 31 (8.05%) are female, and 354 (91.95%) are male workers. Out of 354 male workers, 139 workers (39.3%)

fall in the category of Low SLI, 208 workers (58.8%) in the category of Medium SLI, and the remaining seven workers (2.0%) in High SLI. Whereas out of 31 female workers, only eight workers (25.8%) fall into the category of Low SLI, only one worker (3.1%) falls in the category of High SLI, and the rest 22 workers (71%) fall into the category of Medium SLI. Here, the female percentage in the Medium SLI and High SLI categories is more than males. On the flip side, the percentage of female workers in the Low SLI is less than the male percentage; a possible reason for this anomaly may be that female workers are earning for their families, and their husbands are also working in either the same organisation or any other organisation that makes their income higher than the families with only one earning member.

Table 4. Total SLI * Current Residence Area Crosstabulation

			Current Residence area		Total
			SEMI- URBAN	RURAL	
Total SLI	Low SLI	Count	40	107	147
		% within Current residence area	59.7%	33.6%	38.2%
	Medium SLI	Count	24	206	230
% within Current Residence Area		35.8%	64.8%	59.7%	
High SLI	Count	3	5	8	
	% within Current Residence Area	4.5%	1.6%	2.1%	
Total	Count	67	318	385	
	% within Current Residence Area	100.0%	100.0%	100.0%	

In table 4 above, out of 385 respondents, 67 (17.40%) workers currently reside in the semi-urban area. At the same time, 318 (82.60%) reside in rural areas. As we can see, none of the workers live in an urban area because most of the manufacturing units in the target cities are either rural or semi-urban. The workers primarily reside in the areas close to the factory. Further, it is observed that, out of 67 workers, 40 workers (59.7%) are in the Low SLI, 24

workers (35.8%) are in the Medium SLI, and only three workers belong to High SLI. Whereby out of 318 workers residing in the rural area, 107 workers (33.6%) belong to Low SLI, while in the category of Medium SLI, there are 206 workers (64.8%), and the rest of the five workers (1.6%) fall in the category of High SLI.

Table 5. Total SLI * Number of dependents in the family Crosstabulation

			Number of dependents in the family			Total
			0-3	4-6	7-10	
		Count	80	64	3	147
Low SLI	% within	Number of dependents in the family	43.5%	34.6%	18.8%	38.2%
		Count	99	119	12	230
Total Medium SLI	% within	Number of dependents in the family	53.8%	64.3%	75.0%	59.7%
		Count	5	2	1	8
High SLI	% within	Number of dependents in the family	2.7%	1.1%	6.3%	2.1%
		Count	184	185	16	385
Total	% within	Number of dependents in the family	100.0%	100.0%	100.0%	100.0%

In the above table 5, based on the number of dependents, families of workers are divided into three categories- families who have 0 to 3 members dependent on the earnings of the worker, families who have 4 to 6 members dependent on the earnings of the worker, and the families which has 7 to 10 members dependant on the earning of a worker. There are 184 workers (47.81%) with less than equal to 3 dependants in the family, which of those, 80 workers (43.5%) fall in the category of Low SLI, 99 workers (53.8%) fall in the category of Medium SLI and the High SLI there are only five workers (2.7%). Out of 185 workers (48.05%) with 4-6 dependant members, 64

workers (34.6%) come under the category of Low SLI, 119 workers (64.3%) belong to the Medium SLI, and the remaining two workers (1.1%) belong to High SLI. Out of 16 workers (4.16%) with 7-10 dependant members, three workers (18.8%) belong to the Low SLI category, 12 workers (75%) belong to Medium SLI, and only one worker (6.3%) belongs to High SLI.

Table 6. Total SLI * Education Level Crosstabulation.

		Education Level					Total	
		ILLITERATE	UP TO PRIMARY	UP TO HSC	UP TO SSC	HIGHER EDUCATION		
Low SLI	Count	9	57	65	15	1	147	
	% within Education Level	47.4%	47.5%	34.4%	42.9%	4.5%	38.2%	
	Count	10	61	122	18	19	230	
Total SLI	Medium SLI	% within Education Level	52.6%	50.8%	64.6%	51.4%	86.4%	59.7%
High SLI	Count	0	2	2	2	2	8	
	% within Education Level	0.0%	1.7%	1.1%	5.7%	9.1%	2.1%	
	Count	19	120	189	35	22	385	
Total	% within Education Level	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	

The above table 6 shows, Workers based on their education level are divided into five categories respectively- Illiterate, up to primary level (workers who never went to school but can do basic calculations and workers who study 1st -5th class), up to HSC (workers who studied 6th -10th class), up to SSC (Workers who have completed 12th), and Higher Education (workers who have graduated or post-graduated or hold any vocational degree). It can be observed that out of 19 (4.94%) illiterate workers- 9 workers (47.4%) come under Low SLI, ten workers (52.6%) belong to Medium SLI, and no illiterate workers belong to High SLI. Out of 120 workers (31.17%) who have studied up to the primary level- 57 workers (47.5%) fall under the

category of Low SLI, 61 workers (50.8%) fall under the category of Medium SLI, and only two workers (1.7%) fall under the category of High SLI. Out of 189 workers (49.09%) educated up to High-School- 65 workers (34.4%) belong come under the category of Low SLI, whereas 122 workers (64.6%) come under the category of Medium SLI, and two workers (1.1%) come under the category of High SLI. Out of 35 workers (9.09%) educated up to the level of intermediate- 15 workers (42.9%) belong to the Low SLI category, whereas 18 workers (51.4%) belong to the Medium SLI category, and only two workers (5.7%) belong to High SLI. Further, out of 22 (5.71%) highly educated workers- 1 worker (4,5%) comes under the category of Low SLI, whereas 19 workers (86.4%) fall under the category of Medium SLI, and only two workers (9.1%) belong to High SLI. It can be easily seen that the no. of workers reduces as the level of education increases, but in terms of percentage, as the education level increases, the percentage of workers increases in the High SLI and Medium SLI categories. In contrast, the percentage of workers decreases in the category of Low SLI with the increase in education level.

**Table 7. Total SLI * Person employed other than respondent
Crosstabulation**

			Persons employed other than the respondent				Total
			0	1	2	3	
		Count	92	44	9	1	146
	Low SLI	% within Persons employed other than the respondent	44.2%	33.6%	25.0%	25.0%	38.5%
		Count	115	85	22	3	225
Total SLI	Medium SLI	% within Persons employed other than the respondent	55.3%	64.9%	61.1%	75.0%	59.4%
		Count	1	2	5	0	8
	High SLI	% within Persons employed other than the respondent	0.5%	1.5%	13.9%	0.0%	2.1%
		Count	208	131	36	4	379
Total		% within Persons employed other than the respondent	100.0%	100.0%	100.0%	100.0%	100.0%

Table 7 categorises the number of family members employed other than the respondent worker. In the case of nuclear families, only the parents of the worker or married/unmarried son, or unmarried brother/sister are included. Out of 208 families (54.03%) where no other person than the respondent himself/herself is employed, 92 workers (44.2%) fall under the category of Low SLI, and 115 workers (55.3%) fall in the category of Medium SLI. Only one worker (0.5%) falls under the category of High SLI. Out of 131 families (34.03%) where one person is employed other than the respondent, 44 workers (33.6%) belong to Low SLI, 85 workers (64.9%) belong to Medium SLI, and

two workers (1.5%) belong to High SLI. Out of 36 families (9.35%) where two other persons are employed excluding respondents, nine workers (25%) come under the Low SLI category, 22 workers (61.1%) come under the category of Medium SLI, and five workers (13.9%) come under High SLI category. Out of 4 families (1.04%) where four members are employed other than the respondent, only one worker (25%) falls under the category of Low SLI, and the remaining three workers (75%) fall under the category of Medium SLI. It can be easily observed that in most cases, as the number of people employed other than the respondent increases, their percentage in the category of Low SLI decreases, and the percentage in the category of Medium SLI and High SLI increases.

4.1. Hypotheses Results

The dependent variable (standard of living) was regressed on predicting variables of worker's qualification, caste, and current area of residence. The independent variables significantly predict the standard of living, $F(4, 374) = 10.167$, $p < 0.001$, which shows that all four factors significantly impact the standard of living. The $R^2 = 0.098$ describes that the model demonstrates 9.8% of the variance in standard of living.

Additionally, coefficients were analyzed further to measure how each of the four components affected the touchstone variable (Standard of Living). H1: whether a worker's education level significantly and positively affects the standard of living. The results revealed that workers' education level significantly and positively impacts the standard of living ($B = 0.093$, $t = 3.211$, $p = 0.001$). Hence, H1 was supported. H2 evaluates whether a worker's current area of residence has a significantly positive impact on the standard of living. The results show that the worker's current area of residence has a significantly positive impact on the standard of living ($B = 0.208$, $t = 3.027$, $p = 0.003$). Consequently, H2 was supported. H3 evaluates whether a worker's caste has a significantly positive impact on the standard of living. The results show that workers' caste positively impacts the standard of living ($B = 0.092$, $t = 2.371$, $p = 0.018$). Consequently, H3 was supported. H4 evaluates whether the number of persons employed other than the respondent positively impacts the standard of living. The results show that number of persons employed other than the respondent has a significantly

positive impact on the standard of living ($B = 0.110$, $t = 2.986$, $p = 0.003$). Consequently, H4 was supported.

Table 8. Hypotheses Results

Hypotheses	Regression Weights	B	t	p-value	Results
H1	SL→WEL	0.093	3.211	0.001*	Supported
H2	SL→WCRA	0.208	3.027	0.003*	Supported
H3	SL→WC	0.092	2.371	0.018*	Supported
H4	SL→NDER	0.110	2.986	0.003*	Supported

Note: * $p < 0.05$, SL: Standard of Living, WEL: Worker's Education Level, WCRA: Worker's Current Area of Residence, WC: Worker's Caste, NDER: Number of Persons Employed other than the Respondent

5. Conclusion

In summary, findings on the standard of living (economic status) of informal workers in the manufacturing sector of Uttar Pradesh show most of the workers are living with either Low SLI or Medium SLI, and very few workers can live a decent life. Though the factors like- education, level, the caste of the worker, current residence area, and the number of persons employed in the family have a positive and significant impact on the living condition of the family, these are not the only factors that affect the living standards of the workers.

Under investigation, data shows that female participation as an earning member of the family can significantly affect the average living standard of the family. Workers living in rural areas enjoy not only better living standards but also better social life. Though the nuclear families with a smaller number of dependents are in better living conditions, on the other side, joint families enjoy the benefit of more earning hands and so the benefit of economies of scale. While other factors also significantly impact SLI, higher education can significantly improve the family's economic status.

6. Policy Recommendations

The government must comprehend both the requirements of employers and workers to create effective welfare policies. Medium and small-scale manufacturing facilities, such as sugar, rice, flour, and cattle feed factories, primarily employ low-skilled or unskilled informal labour, resulting in low productivity and low-profit margins. Additionally, it has been reported that

the government compels these companies to accept agricultural products offered by farmers, even of inferior quality, which further diminishes their profit margin and compels them to pay their workers to lower wages. Along with the minimum wage, the government needs to revise agricultural produce pricing and quality standards from time to time. Furthermore, the government must offer subsidies for these small manufacturing facilities because MSMEs account for 33% of India's manufacturing output and 45–50% of its exports in the textile, food processing, chemical, and electrical or equipment industries.

In order to strengthen workers' social security and their potential for collective bargaining, labour unions must be encouraged in rural and semi-urban regions. Furthermore, beginning skill-development programmes for workers of MSMEs will benefit workers by fostering job security and boosting worker and organisational productivity. However, before that can happen, the government must make workers aware of the value of joining a union and its advantages.

7. Limitations of Study

This research is confined to some districts of Uttar Pradesh and only covers some issues of informal workers in the manufacturing sector because of the cost and time restraints. Further, due to the low education level of the respondents, responses are not 100% reliable. Though the research results cannot be universally applicable, they would apply to research areas with similar characteristics.

Notes:

1. Instead of taking land holding as a variable of the standard of living, the approximate value of land holding is taken as a variable because the value of land differs on the basis of where the land is situated. So, the value of land shows a more significant impact on SLI.
2. By the standard of living of workers, we mean the economic condition of the household they live in.

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SOME STEPS TOWARDS GENDER EQUALITY: A
ENTREPRENEUR IN SUPPORT OF WOMEN IN ITALY 1920-
1940

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Abstract

The issue of the role that firms and entrepreneurs played as regards the emancipation of women in the workplace and in society is still open to analysis, especially in Italy. With the literature sorely lacking, our paper is an attempt to offer further insights, focusing on the two decades when Fascism held sway in Italy.

The context is unique. Fascist ideology ran contrary to the affirmation of women in the workplace. At the same time, because of the country's colonial wars and the events of World War II, the Italian productive system suffered from a growing paucity of male workers, especially in some strategic sectors. To ensure the continued operation of their factories, some entrepreneurs were amenable to the idea of taking on female employees and workers. These entrepreneurs had an opportunity to positively shape the road to emancipation for women. But were they able to make full use of this opportunity, or was it something temporary, possibly motivated by the circumstances of profit alone? What role did the integration of female workers and employees play in shaping company management policies?

Our essay intends to answer such questions by analysing the case of Leopoldo Parodi Delfino, one of the most important Italian entrepreneurs during the wartime period as he wrote a significant page in the field of work for women.

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Some steps towards gender equality: a entrepreneur in support of women in Italy 1920-1940

Even if initially motivated by circumstances to employ women in his explosives factory, Parodi Delfino quickly understood that fostering gender equality could create a conducive environment for a strong work culture and, therefore, for profit.

He went on to launch a series of activities focused on enterprise-centred gender coexistence, a new approach to workplace issues, and the adoption of innovative welfare policies.

This essay focuses on the role played by entrepreneurs such as Parodi Delfino, including the welfare tools designed for the workforce as a whole that might ensure a progressive form of integration within the company while supporting gender equality.

JEL CODES: N00; N34; N84.

KEYWORDS: WORK; GENDER EQUALITY; FASCISM; ITALY; COMPANY WELFARE

1. Introduction

This essay will trace the path followed by Leopoldo Parodi Delfino (1875-1945), a well-known Italian entrepreneur. During his tenure as head of Bombrini-Parodi Delfino (BPD), considered a vital business during the Fascist regime as it manufactured explosives, he focused the company's strategy on modern, inclusive economic and social models that included employing women in a sector typically considered "the province of males" (Bourdieu, 1998).

We'll outline the plan that Parodi Delfino followed and analyse the company welfare policies he adopted for BPD. Starting in the Twenties, Parodi Delfino decided to move away from Fascist propaganda (where females were seen as procreators to be controlled by men) to more inclusive policies that placed males and females' shoulder to shoulder in the workplace. What pushed Leopoldo Parodi Delfino to go against the Fascist ideology and the policies adopted by other entrepreneurs of the time as regarded women and work? Why did he employ females in BPD's factories and why did his company pursue a corporate welfare policy which effectively was one of the first in Italy to promote parity between the sexes?

This paper will highlight the first attempts toward this employment model with its particular focus on women and gender equality. Gender equality has been studied for more than a half century through research projects and presentations, as well as during international conferences discussing gender (Fraser, 1997). Starting in the 1990s, gender equality became the object of periodic assessments via indexes and rankings such as those proposed by the European Institute for Gender Equality (Norlen, et al., 2009, p. 6).

The evolution towards equality that started in the first years of the 20th century involved Italy just as much as other nations of the Western world. Scholars have diachronically examined, albeit through different approaches, the evolution of gender equality, considering both its positive aspects as well as the elements which slowed down its achievement. Among the former, we think that the decisive role of economic expansion is especially important; improved living standards had a positive effect on the relationship between the sexes (Goode, 1963; Mitra et al., 2015). Such a vision is shared by many researchers who have highlighted the link between gender equality and development. As the status of both sexes changed in the workplace, overall economic progress advanced. The effect spilled over onto family and social conditions which also improved (Goldin, 2006; Klasen & Lamanna, 2009; Crowley, 2016; Croucher & Økland, 2021).

In other research it has been noted that whenever women decided to stay at home to care for children on their own, there was an obvious advantage for men and their jobs, resulting in an interruption towards gender equality (Becker, 1991). Some scholars have blamed the lack of gender equality on smaller investments in personal and professional training for women (Mincer & Polachek, 1974; Tam, 1997). Finally, an important part of the relevant historiography has traced the limits of equality between men and women back to differing cultural factors in nations and ethnic groups that affected the economic milieu as well (Gunderson, 1989).

Even if it isn't difficult to find significant and widespread examples of female employment in Italy during the 20th century (for example, in the textile and clothing industries), gender equality studies tend not to consider the role that entrepreneurs played (Maineri, 1930, pp. 295-296). This paper would like to add something to the discussion by examining Parodi Delfino's choice to adjust business strategies to accommodate the presence of women in BPD's manufacturing facilities. This tactic highlighted the natural flexibility that female workers could offer and turned out to be a winning factor for BPD during the years of autarky.

The politics of autarky called for increased manufacturing in strategic sectors while, at the same time, reducing the number of women employed in traditional industries like textiles. In northern Italy, in fact, contractions in international commerce led to a surplus of women in the workforce; only some of them could be reabsorbed in sectors traditionally dominated by men (Sabbatucci Severini & Trento, 1975, p. 566).

By studying company documents, parliamentary acts, grey literature, oral sources and an extensive series of reference literary sources, our essay analyzes whether-- and how-- the integration of female workers into the factory had an influence on company welfare and what effect the new labour model subsequently had on the local reality. In order to give voice to these women, we read the diaries of factory girls that can be found in various archives.

The essay is structured as follows: following this introduction we outline the historical economic context between the two world wars that characterized Parodi Delfino's entrepreneurial experiences. Then we examine the corporate welfare system as a form of business governance before taking a look at the situation of women during the years of fascism. This leads us to review female occupation in the Italian explosives industry and to an analysis of the entrepreneurial figure of Parodi Delfino and BPD, his manufacturing concern.

2. The historical context

The historical period between the two world wars was characterized by strong economic jolts and a situation where the Fascist regime first seemed to incarnate the response to the worker unrest that permeated the "biennio rosso" (two red years) but eventually ended up embodying the solution to the age-old conflict between property and workers, through a relative pacification between "capital and labour", something that was reflected in the Fascist corporative system (Gentile, 2001, pp. 204-208; Id., 2004, pp. 101-111).

In effect, a kind of industrial capitalism that seemed to be inclined towards listening to the demands of the "people" (theoretically at least) arose. De facto, as noted in a diary entry by Ettore Conti, a magnate of the electric industry, often a single person dominated an entire branch of an industry. This can be seen in the stories of entrepreneurs such as Giovanni Agnelli (automobiles), Alberto Pirelli (tires), Guido Donegani (chemicals), Giorgio Enrico Falck (steel), Vittorio Cini and Giuseppe Volpi (utilities) (Conti, 1946).

3. Company's welfare as a corporate governance tool

During the interwar period, there was a marked change in the corporate attitude towards workers. The well-being of workers was no longer limited to factories but was considered within the relevant social context instead (Miller, 1981). As a matter of fact, this was an evolution of traditional paternalism, aimed at achieving greater productivity (Baglioni, 1974; Romano, 1965). Company welfare became a tool to promote "peace" between entrepreneurs and workers (de Grazia, 1978).

Entrepreneurs began to adopt this new model of labour governance at the time that the lira's revaluation and the economic policies of the Fascist government started seriously impacting the living standards of the working class. As a matter of fact, it was the government that spurred company managers to apply in their factories the services and benefits in favour of the actions required to achieve a greater degree of productivity and competitiveness in international markets. These were done together with rigid and decisive interventions in the field of social struggle. Fascist company welfare, focused on establishing itself as a *modus operandi* in factories, intended to move and bring the Italian industrial fabric closer to that of overseas realities (de Grazia, 1978). Such a goal became a reality via the new dynamics of factory management that focused on a better sharing of the workload and on actions undertaken on behalf of the workers that were designed to increase their well-being and consumption of goods (Sassoon, 2019).

The Fascist regime also implemented a series of measures (including compulsory insurance against accidents and occupational disability as well as for tuberculosis) that would better protect the working class and increase work-related pensions (Demier, 1989, p. 30). In 1934 the government granted family allowances, both to workers and the unemployed, while also providing support for some kinds of public and private employees (Girotti, 2004, pp. 195-196). In 1925 controlling the working class became easier with the creation of the *Opera Nazionale del Dopolavoro*, a national entity focused on recreational activities for workers. This initiative, together with political party sections, ensured a special, direct and ubiquitous form of worker surveillance (Benenati, 1994, pp. 185-186).

We examined some social and company policies which went hand in hand with consensus and its tools (Benenati, 1997, pp. 71-73). Entrepreneurs were involved in a process of responsibility, as well as in the social control of the

country, something whose economic impact was proven by the production efficiency and the results achieved in terms of profit, which proved vital in assessing company management. Confindustria, the principal association of Italian manufacturers, also made its contribution by opening offices that focused on supporting workers (de Grazia, 1981). These provisions connected positively with the growth of Italian industry, in particular with those companies working in the war sectors and their related activities; starting in the 1930s these firms were supported by the Italian national rearming program (Cova, 2002, p. 542).

Still, company and employment policies gave little consideration to the role of women who, in the majority of cases, were pushed away from employment and were not guaranteed even the limited emancipation that they had achieved during the early 1900s, especially in the wake of World War I. Indeed, women were seen almost exclusively as wives and mothers. However, it should also be mentioned that such a vision was by no means the most common; some entrepreneurs started to employ female workers even in sectors where male workers had traditionally been predominant.

Leopoldo Parodi Delfino, an engineer by training, was one of these business leaders. Even if he has not been studied much up to now, he was a well-known protagonist of the Italian economic scenario of the early 20th century. Among the strategic choices he adopted was one (in actions as well as words) that allowed males and females to mingle in the workplace.

Within every division of BPD, workers were considered an important part of an overall strategy. The workplace, where great care was taken to ensure that it was both liveable and tranquil, was based on cooperation between entrepreneurs and workers with a special attention for the women who were supported and encouraged to give their level best in their factory work.

4. Some contradictions in the interactions among women, employment and Fascism

The transition from the liberal system to the Fascist regime marked the end of many of the advancements achieved during the previous years for female workers. Once again, women were relegated to their role as procreators and homemakers (Imbergamo & Scattigno, 2006; Bensa, 1919; Scott, 1991; Vaccari, 1978, p. 27).

There was a clear regression of women in both society and the workplace. By continuing to deny women the right to vote, the path toward parity between the sexes that started to manifest itself in many industrialized nations was further delayed in Italy. In 1917 universal suffrage had become the norm in Russia. The next year the right to vote was extended to women in Canada and in England. In 1919 women in Czechoslovakia, Poland, the Netherlands, Germany and Luxembourg were granted the vote. In the Twenties the vote was extended to women in Belgium, the United States, India, Pakistan and Sweden. In the 1930s women in South Africa, Ceylon, Thailand, Turkey, and Cuba were able to vote (Taricone, 1992, pp. 341-364).

The Fascist government imposed harsh restrictions on female workers via legislation like the June 1939 decree that put limitations on their presence in both private as well as public workplaces¹.

With the elimination of the practice of permitting a woman to work if she had her husband's consent, the gains made earlier (including recognition of legal capacity and full access to jobs) were cancelled, leading women to experience setbacks in both status and dignity (Ticozzelli, 2016, p. 7).

The Fascist regime openly discouraged female employment outside the home with the government espousing the perceived natural inferiority of women: "men are vastly superior to women" (Meldini, 1975, pp. 31-35; Oriani, 1923). Such an assumption was based on the idea that motherhood was the role most suited for exalting femininity (Marchianò, 1980, p. 753). According to Fascism, the duty of a woman to the nation was to be a mother and bear children (de Grazia, 1993), even if such a role was at odds with the other one where she was expected to be "silent and always available, both as a female citizen and patriot; she was to be present, that is to say ready to fight and to be called upon" (Benadusi, 2014, p. 192).

And Mussolini, too, did little to conceal his thoughts on the matter. In his May 1927 "Ascension Day speech" Mussolini affirmed that Italy needed its women for "births, many births" as the "fate of the race" had to be watched [...] "starting with maternity and childhood" and the nation "had to be [...] demographically whipped into shape" (Mussolini, 1927).

The Church shared similar ideas on women workers (Baglioni, 1967, pp. 242-259). The prevailing thought within the Catholic world was to limit and oppose the presence of women in the workplace so as to restore the righteous

¹ Repertorio Generale. *Annale della Giurisprudenza Italiana*, Turin: Utet, 1948, p. 1088.

social order (Schoeni, 2012, p. 555). Such an axiom was contained within Papal bulls as well with declarations affirming that “family mothers [had to work] at home or nearby, in order to perform housework” (Pius PP. XI, 1931, 297).

The Fascist government promoted an image of a family where conflicts between men and women did not exist because both sexes were “truly united towards a higher purpose, that is to say the perpetuity, strength, and superiority of any given lineage”. In effect, the centuries-old clash between the sexes was resolved with the expectation that women would take a step backwards for the good of the family and the nation (Bruschi Gorjoux, 1934, p. 69).

Female independence was discouraged; as such it was considered unnatural for women. In order to achieve this goal, intense propaganda activities were carried out, promoting an increase in birth rates and forcing the “fairer sex” into roles of wives and mothers. The government set up incentives for its demographic campaign that included jobs, career advancement, salary benefits for men with large families, loans for births and marriages, donations for large families, maternity insurance policies, and the like. Propaganda efforts also focused on contraceptives (Passerini, 1983, p. 87) and, in 1927, even bachelorhood was taxed “(men who continue to remain) bachelors shall pay as follows: 35 Lire from 25 to 35 years of age, 50 Lire from 35 to 50 years of age, 25 Lire from 50 to 65 years of age [...]. Arrest shall be the maximum form of punishment”².

In fact, the population increased but this was due more to lower infant mortality and to the progress of medical science against “common diseases” (Ritter, 2003, pp. 240-241), rather than to trends in birth rates; such rates decreased during the 1921-1940 period, from 31 to 23% yearly (Istat, 2019, p. 3). The resulting situation led the Fascist regime to antagonize working women even more as they were considered the architects of the “economic-moral crisis of the family” (Orano, 1937, p. 4): “Employment for women creates two kinds of damage: the masculinization of women and an increase in male unemployment. Working women are on their way to infertility; they [...] contribute to the corruption of customs and, in short, pollute the lives of their lineage” (Danzi, 1935, p. 27).

Jobs for women were opposed in any and all sectors and contexts; female employees were deemed a threat to morality (Loffredo, 1938, p. 365): “it is

² *Gazzetta Ufficiale*, no. 39, 17 February 1927, pp. 741-742.

known for a fact that female delinquency is higher in those countries with a greater presence of females in the workplace while it is less widespread where women work the land and even lower where women engage in housework alone” (Pende, 1933, p. 135).

At the same time that the government expressed opposition to female employment it also dedicated a certain degree of attention to pregnant female employees, protecting them both as mothers and as members of the workforce. The approval of the Royal Decree-law no. 850 of May 1929 with its provisions for the protection of female employees during pregnancy and the postnatal period was significant in this regard³:

The law herein has a very significant demographic and social meaning, as it aims to assist maternity by ordering the removal from work of female workers and employees during the last month of their pregnancy, as well as during the month following childbirth, with all the benefits of job retention, insurance, and the like⁴.

In contemporary, the Fascist government continued to propose solutions designed to limit the presence of women in the workplace⁵. Women were to be phased out from the available jobs. Such a solution would have placed women as subordinates of men for good (Loffredo, 1938, p. 365). Practically speaking, several such initiatives existed, starting with the school environment where, although women were instinctively geared towards education, in effect they lacked that kind of “virile and martial” strength that Fascist Italy needed and felt that only male teachers were able to ensure. Male instructors were necessary in order to prepare future citizens who were “filled with a strong feeling of their nationality and the prestige of the Fatherland”⁶.

Still, in the 1930s a change of heart occurred in the original vision of women as mothers; it happened at the same time an autarchic policy aimed at achieving the economic independence of the nation was advanced. In order to

³ Camera dei Deputati, Royal Decree-law, no. 850, 1929, *Concernente disposizioni per la tutela delle operate e impiegate durante lo stato di gravidanza e il puerperio*, Parliamentary Acts, Session I, Discussions, Round of voting held on 20 June 1929, pp. 1285-1286.

⁴ *Ivi*, p. 1285.

⁵ Royal Decree-law, no. 989, 1939, set up the kinds of jobs and activities that were the province of female employees, in the public and private sectors.

⁶ Camera dei Deputati, *Discussione del disegno di legge: Stato di previsione della spesa del Ministero dell'educazione nazionale per l'esercizio finanziario, July 1, 1930-June 30, 1931 budget*, in Parliamentary Acts, Session I, Discussions, Round of voting held on 28 March 1930, p. 2024; *Id. Discussione sul bilancio dell'educazione nazionale*, Round of voting held on 13 May 1931, pp. 4660-4672.

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encourage agrarian employment, the government turned its attention towards females: an increase in the agrarian workforce was necessary to support both the sector activity and to increase production. The crucial importance of such an objective led the government to consider innovative measures in favour of women. In the parliamentary sphere, the possibility of female vocational-agrarian training was taken into consideration. It was all about expanding basic knowledge in order to support women when agricultural management tasks were concerned. For the first time, vocational education for women was part of an overall reform plan⁷.

Such a policy encouraged the shift of activity for women from family to employment, highlighting the discrepancies in the Fascist ideology that had, as mentioned above, exiled women to their families, yet also protected them when their employment and basic education were concerned. Still such a support stopped with agricultural activities (Sabbatucci Severini & Trento, 1975; Fuà, 1975).

Parodi Delfino followed the very same path, supporting women as they accessed their jobs in the BPD factory situated in Colleferro, a town not far from Rome. His plan called for assisting women in both their work and family related activities.

5. Female employment in the manufacturing industry of explosives during the Fascist period

The analysis we carried out highlights the presence of women in the workplace even in light of the ideological ostracism of the Fascist regime which actually protected female workers. Our research is based on general census data for Italy, especially considering the data from 1921, 1931 and 1936, provided by Istat, the Italian national statistics institute (Table 1).

⁷ Camera dei Deputati, *Discussione del disegno di legge: Riordinamento dell'istruzione media tecnica*, in Parliamentary Acts, Session I, Discussions, Round of voting held on 22 May 1931, p. 4886.

Table 1. Working population and gender ratios in the workforce (1921-36)

YEARS	Working population (in thousands)			Percentage in the workforce by gender	
	Males	Females	total	Males	Females
1921	12,299	5,169	17,468	84.1	34.2
1931	13,124	5,088	18,212	86.2	31.6
1936	13,341	5,242	18,583	83.1	31.1

Source: Istat (2011), p. 468.

Between 1921 and 1936, the number of men in the workforce increased while the female component, albeit with some fluctuations, experienced a smaller increase, arriving at 5.24 million. Even more significant were the percentages of men vs. women in the workforce. Data from the three years show that more than 80% of males of the population of working age were employed while for females the percentage fluctuated between 31 and 34% when referred to the same demographic.

The limited presence of women in the workplace was a reflection of the legislative provisions of the era. On the one hand, these provisions protected women (for example during their working hours, weekly rest periods, safety measures, etc) while at the same time effectively encouraging their removal from the workforce as these protective measures effectively increased the costs for employers to hire women. Ultimately, employing women proved to be unwieldy, at least in theory, for many private sectors making it preferable to hire unemployed men (Ritter, 2003, p. 244). Women in the cities gravitated towards finding employment as domestic workers, something that was made official when in 1937 the Fascist government established SOLD (Section for female laborers and home-workers) (Musso, 2003, p. 13).

But the trend of women employed in the explosives sector was completely different from the national context of the time. In the two decades of the Fascist regime, in addition to the BPD facility in Colferro there were gunpowder factories in Avignana (Turin) and Spilamberto (Modena) as well as the Royal gunpowder factory in Fontana Liri Inferiore (Frosinone), the only State-run factory⁸ to employ a predominantly male workforce. While the 1921

⁸ The Historical Archive of the Information Centre for the Municipality of Colferro (ASCColferro, from its Italian acronym), Bombrini Parodi Delfino (BPD), Materials to be sorted (M.a.o, from their Italian

census showed just 628 female workers in the sector, over the next ten years their presence tripled, eventually reaching 9135 by the late Thirties.

Table 2. Workers in the explosives sector in Italy (during the 1921-40 period)

Number employed in the explosives sector in Italy			
Year	males	Females	total
1921	4022	628	4650
1931	4222	1815	6037
1936-40	35,244	9135	44,379

Source: Authors' own elaboration of data from: Istat (1928), *Censimenti della popolazione del Regno d'Italia 1921*, pp. 156-157; Istat (1934), *VII Censimento Generale della popolazione, 1931*, pp. 160-161; Istat (1939), *VIII Censimento Generale della popolazione, 1936*, pp. 19-20.

Most of the women employed in the sector worked either in the Stabilimento Italiano Prodotti Esplosivi (SIPE) factory in Spilamberto owned by the Quartieri family or in the BPD factory of Colleferro. At the latter Parodi Delfino had begun hiring female workers as early as 1925 (Nova, 1993, p. 7), spurring the arrival of women from beyond the region as well. While the two factories were competitors, they regularly communicated with each other as shown by letters exchanged between managers at SIPE and at BPD⁹.

Parodi Delfino became a pioneer of systematic integration between men and women in the workplace, favouring equality between the sexes both directly and indirectly, despite the official vision touted by the Fascist regime.

Thus, the foundations for the presence of women working in the national production sectors were laid. As it found good ground in the needs of profit, as well as in the features of that historical period, Parodi Delfino's example quickly spurred others (including BPD's competitor, SIPE) to open the doors of their factories to female employees, all while half-heartedly adopting progressive welfare policies as well.

acronym), *25 anni di vita della B. P. D., Relazione del dottore Tito Benelli, direttore della fabbrica, ottobre 1912-ottobre 1937*, 6; Ivi, *Origini dello stabilimento BPD di Colleferro, Relazione del dottore Aldo Colajacono*, 24 February 1966, p. 9.

⁹ ASCColleferro, BPD, M.a.o., *Relazioni epistolari tra la BPD e la SIPE. Studio teorico pratico sui razzi dallo stabilimento di Spilamberto no. 13*, February 1936.

6. Leopoldo Parodi Delfino: the engineer-entrepreneur

Leopoldo Parodi Delfino came from an affluent middle-class family in the northwest area of Italy. An engineering degree from the ETH Zurich and specializations at the universities of Leipzig and Wroclaw were the cornerstones of his skills as an entrepreneur and a manager. His style was similar to that of the new breed of industry captains like the Pirelli, Crespi, Cantoni and Falck families. These families adopted a management style that was different from the ones who, during the early post-unification phase, relied on the support of the Italian State above all (Toscano, 2014).

In 1902, after a brief spell in the family distilleries, he founded his first undertaking, the “Società Fabbrica Nazionale Alcool Leopoldo Parodi-Delfino”, legally headquartered in Milan but with manufacturing facilities two hundred kilometres away in the city of Savona. Not yet thirty years old, two years later he expanded his business with the establishment of “Società Anonima Distilleria Nazionale per l’alcool da melasso” based in Pontelagoscuro (in the province of Ferrara); it was the first Italian company to produce neutral ethyl alcohol made from beet molasses, a process that permitted a drastic reduction of the costs of imported alcohol. Parodi Delfino’s activities in the sector continued as he took part in “Società Distillerie Italiane,” a productive aggregation of more than 20 operations; he chaired Società Distillerie Italiane for about a decade¹⁰. Finally, in 1907, he entered the winemaking sector by buying the “Società Anonima Vinicola Italiana Florio & C.” based in Marsala and taking on the role of company CEO.

In 1906, Leopoldo Parodi Delfino had decided to diversify his interests. Together with two important Italian business leaders, Giovanni Bombrini and Ferdinando Maria Perrone (from the engineering firm, Gio. Ansaldo & C.), they established “Società in accomandita Ercoli Antico e Soci” (Attolini, 1915, p. 15), a company involved in the construction of important infrastructure projects in southern Italy that attracted substantial State contributions. Among the projects was the Apulian Aqueduct (Società Concessionaria dell’Acquedotto Pugliese, 1915, pp. 3-4). “Ercoli Antico e Soci” was awarded the contract and started work in early 1906 but it soon began to accrue debts and delivery delays due to a series of unfavourable circumstances including the international economic crisis of 1907, the 1911

¹⁰ ASCColleferro, BPD, M.a.o., *Origini dello stabilimento BPD di Colleferro*, p. 10.

cholera epidemic and then the outbreak of World War I. In 1919 the government was forced to entrust these infrastructure projects to the “Società Anonima Italiana per Opere Pubbliche e Imprese Industriali” with Parodi Delfino as its president¹¹.

Meanwhile, in 1909 Parodi Delfino had also entered the field of enamelled iron production, becoming a founding partner, as well as president, of “Società Smalteria Italiana” company in Milan (BPD, 1962, p.7).

At the beginning of the second decade of the 1900s, Italian Prime Minister Giovanni Giolitti involved Parodi Delfino in a project that was ambitious as well as of vital importance for the nation-- the manufacture of explosives. In order to do this, working with Giovanni Bombrini (the son of Carlo, one of the founders of the Ansaldo company as well as director of the National Bank of Italy), they established “Società Bombrini Parodi Delfino” (BPD) in 1912. In 1921 production capacity expanded to include a manufacturing plant for pozzolanic cement and lime.

In the following years Parodi Delfino took part in initiatives in other sectors as well: in the field of electricity, he was one of the founders of “Società Mediterranea di Eletticità” (1918). That same year he was involved in Soie de Châtillon’s production of a new fiber, viscose. Under his direction, the Aosta company became an industry leader and opened two new factories in nearby Ivrea and Vercelli (Toscano, 2002, p. 83).

In 1918, on behalf of the government, he became the fiduciary manager for “Miniere e Stabilimenti e Asfalti e Bitumi” (asphalt and bitumen) as well as “Reh & C.” and of “Società Valle Romana”; the latter had been requisitioned from the Germans¹².

At the end of World War One, Italian economic policies encouraged investments abroad (V.E. Orlando, 30 October 1917-23 June 1919). Taking advantage of this policy, in 1918 Parodi Delfino established “Société des mines de Selenizza”, a firm in Valona that would carry out mining and oil exploration activities. Over 500 employees worked in the company and its yearly production amounted to about 20,000 tons of bitumen (Damiani, 1980).

In 1921, he invested in Ecuador, where, thanks to the financial support of BPD, he established the “Compagnia Italiana dell’Equatore” (CIDE) company, together with Banco Italiano, the local Italian bank, in Guayaquil

¹¹ Bollettino Ufficiale del Ministero dei Lavori Pubblici, no. 19, 1919: pp. 1808-1809.

¹² ASCColleferro, BPD, M.a.o., *Promemoria Attività Leopoldo Parodi Delfino*, p. 3.

(Soave, 2008, pp. 67-68). While supported by the Italian government, these entrepreneurial initiatives were hindered by the great foreign powers, in particular the United States, which aimed to create an exclusive role in Ecuadorian economic development. Nonetheless, both the Banco and CIDE did not eschew their activities in the Andean country, integrating themselves into the financial fabric of Ecuador perfectly, as they promoted the construction of public infrastructures and other facilities, such as government buildings, hospitals, and some religious structures in the capital of Quito (Soave, 2008, p. 72). However, in 1936, during autarky, CIDE, as happened with other national foreign investments, was liquidated by the Fascist government in order to recover capital that would be applied to Italy's participation in the Second World War (Soave, 2008, p. 159). Finally, in 1941 Parodi Delfino founded "Valorizzazione Idroterapia Radioattività Ischia-Lacco" (V.I.R.I.L.) (hydrotherapy treatments) with share capital of 10 million lire and purely scientific goals¹³.

During the Fascist regime, Parodi Delfino often adapted his tactics to the new political context. In order to protect his numerous undertakings, in 1932 he joined the National Fascist Party, as did several entrepreneurs, including Giovanni Agnelli. To justify membership in the Fascist Party, Agnelli is said to have reminded his colleagues that "entrepreneurs are ministerial by definition" (Castronovo, 1995, pp. 129-135).

Parodi Delfino thus became an important actor in the Fascist National Federation of Chemical Industrialists. He was awarded various honors and appointments. In 1932 he was named the President of the provincial council for corporations in Rome. Five years later he was honoured with the title of "Cavaliere del Lavoro"¹⁴ and, in 1939, became a Senator for the Kingdom of Italy, as well as a member of the Italian National Fascist Union in the Senate (UNFS, from its Italian acronym). He was a member of several Commissions, such as Finance, Corporative Economy and Autarky, and the Armed Forces. In the reports he wrote, he tried to exercise a certain amount of autonomy, even as he cautiously distanced himself from the Fascist ideology¹⁵.

¹³ Historical Archive of the Italian Senate (ASSR, from its Italian acronym), Ufficio di segreteria, Acts connected with appointing Senators, Senator Files, unit 1664, Leopoldo Parodi Delfino, 27; ASCColleferro, BPD, M.a.o., *Leopoldo Parodi Delfino. La sua vita, il suo lavoro*, s.d.

¹⁴ ASSR, Ufficio di segreteria, cit., p. 7-bis.

¹⁵ Ivi, pp. 15-16.

His uncompromising style, in both economics and politics, earned him the moniker “Iron Senator” (de Orleans-Borbon, 2011). As previously mentioned, he was able to deftly adapt himself to the twists and turns of political power; this provided him with a certain freedom of action. His activities as Senator of the Kingdom of Italy were considered immune from any grovelling and subservience to Fascism conformism, since, as a member of the various committees to which he belonged, he just spoke “on a few bills, all of them technical in nature, providing several critical remarks and proposals for amendments”¹⁶. This affirmation can be found in the judgment of the High Court of Justice for the sanctions against Fascism, which sued him pursuant to the Italian Legislative Decree no. 159, issued on 27 July 1944, also known as “Sanctions against Fascism”.

Since he was a conformist in this as well, after 8 September, Parodi Delfino was not afraid to approach the Italian partisan movement, producing weapons and ammunition for them in his Colleferro plant¹⁷. He was cleared of any wrongdoing only after he died in 1945. During the hearing of February 1947, the Judicial Chamber of the High Court of Justice, responding to a request by Parodi Delfino’s heirs, recognized that the circumstances that might have required him to “no longer be considered a Senator”¹⁸ did not exist (Amatori & Colli, 1999).

7. The Bombrini Parodi Delfino’s company: the origins and evolution of a strategic industry

Leopoldo Parodi Delfino is better known for his business ventures and for the political role he played as a Senator of the Kingdom of Italy (1939)¹⁹, than for his progressive entrepreneurial ideology as expressed through the way he conceived women’s work in a society that was increasingly industrialized (de Orleans-Borbon, 2011, p. 51). Through Bombini Parodi Delfino (BPD), his factory combined the productive and main social features of the time. They included women in the workplace and a series of welfare interventions that were extended to include female employees. Parodi Delfino’s managerial

¹⁶ Ivi, p. 11.

¹⁷ Senate of the Kingdom of Italy, *Relazione dell’Alta Corte di Giustizia per le sanzioni contro il fascismo*, 22 February 1943.

¹⁸ ASSR, Ufficio di segreteria, cit., p. 28.

¹⁹ Ivi, p. 27.

vision differed from the official Fascist ideology which preferred to exalt women exclusively in their roles as wives and mothers and discouraged them “from managing the vital features of both institutions and society” (Addis Saba, 1988, p. 5).

BPD Company was the outcome of an agreement between Leopoldo Parodi Delfino and Giovanni Bombrini, also a Senator. The project offered Giovanni Bombrini the opportunity to follow the family tradition established by his father, Carlo. Once more he could be a protagonist of the national industrial scene after having transferred the management of Ansaldo (one of the most important engineering concerns) to Ferdinando Maria Perrone in 1903 (de Orleans-Borbon, 2011, p. 11).

BPD was established as a partnership in order to avoid possible takeovers by banks and manage potential information leaks that would have been beneficial to competitors²⁰. The undertaking was turned into a limited company in 1919, first in the form of a limited partnership (featuring share capital of ten million lire) and then, in 1937, as a limited company (with share capital of twenty million lire)²¹.

With its more than 6000 employees (Toscano, 2002, p. 83) BPD was one of Italy’s most significant industrial groups during the interwar period. It oversaw other companies, including BPD Commercial Company, Società Produzione Calce e Cementi di Segni (the first cement factory in Italy dedicated to the production of hydraulic pozzolan binders) and other smaller production companies (BPD, 1962, p. 122).

BPD’s notable productive and structural features allowed the company to implement managerial strategies that aimed both at growing the business while also pursuing a rational expansion (Chandler, 1962; Amatori, 2010, p. 574). The company utilized an important factory with cutting-edge technology and production capacity. This made it possible for BPD to quickly make its way to the top of the explosives sector as most of the competitors operated with facilities that were obsolete and too small²².

²⁰ Historical Archive of the Ansaldo Company in Genoa, Bombrini Parodi Delfino Company, 1912-1936, *Carlo Raffaele Bombrini, Carte relative alla società BPD, 18, Promemoria di Leopoldo Parodi Delfino*, June 1912, c. 4.

²¹ Historical Archive of the Chamber of Commerce, Industry, Crafts and Agriculture in Rome (ASCCIAARoma, from its Italian acronym), *Bombrini Parodi Delfino*, folder 86-15, volume I, Budget for 1927.

²² ASCColleferro, BPD, M.a.o., *Origini dello stabilimento BPD di Colleferro*, cit., p. 9.

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BPD's managers reported to a team of engineers specialized in the chemical sector; the two groups worked together to design strategies and production lines (Amatori & Colli, 2011).

The Colleferro plant contributed significantly to the town's production of war materials. The manufacture of dynamite and ballistite was started in 1914²³; at its peak, the factory produced twenty-two thousand kilos of ballistite and five thousand kilos of dynamite each day. At the government's request, new weapons (including grenades, incendiary bullets and TNT²⁴) were also added to the production roster.

When World War II came to an end, the company converted its economic activities from warfare-based to the chemical and agricultural sectors by producing sulfuric acid, glycerine, soil enrichers and fertilizers.

8. BPD company and the construction of a village for employees in Colleferro

As it expanded production in the 1930s, BPD acquired the status of a state-of-the-art factory, attracting workers from beyond the region where it was based. The area of Colleferro was transformed by infrastructural projects into a factory town, a familiar model in Italy in the period between the two wars.

It was then that BPD consolidated its social policies. Starting in 1913, the company financed various projects including, among others, the construction of a workers' village designed by Michele Oddini, an architect from Piedmont who had planned similar projects. In an area of about 170,000 square meters, Oddini's blueprint included 200 apartments with a total of 700 rooms. Between 1917 and 1918 the village underwent extensive development, with roads, green spaces, as well as health facilities and recreational attractions (de Orleans-Borbon, 2011, p. 27). As it fully embraced the main welfare issues promoted by the government (Torti, 2009, p. 237), BPD's facilities strengthened ties between the company and its employees.

“Some special and farsighted institutions have been established by the most important industrial companies and such institutions tend to improve the conditions of employees and their families, both during their working hours and rest periods.

²³ ASCColleferro, BPD, M.a.o., *25 anni di vita della B. P. D.*, cit., p. 5.

²⁴ Ivi, p. 6.

Such institutions represent a step towards the general movement that is preparing to finally recognize the mutual, equal interests shared between capital and labour. [...] These institutions achieve fully satisfactory results and compensate for the expenses required for their development and the wear and tear, by increasing work efficiency” (Giani, 1923, p. 1).

In the mid-1930s the industrial village was expanded. Additional capacity was needed in order to house the growing number of workers drawn to Colleferro as the war campaign in Africa had stimulated a boom in production (de Orleans-Borbon, 2011, p. 79)²⁵. Between 1934 and 1936, the residential units doubled²⁶ and additional recreational facilities were built (Lepore, 1993).

The provision of services and housing for workers near its factory satisfied multiple needs—those of the regime which sought social control and political consensus and those of BPD that could count on being able to summon employees at a moment’s notice for substitutions or double shifts. The industrial village had other positive effects-- reducing conflicts at work (due precisely to the “forced” socialization of workers outside the plant) and ensuring the presence of a skilled workforce that identified with the company (Danesi Squarzina, 2002).

Quickly the production facilities in Colleferro became a “hotbed of political activity, as well as an important tether to organize support and urban social life” (Benenati 1997, p. 68). The industrial village was a cornerstone of the sharing process between entrepreneurs and the working class (Covino, 2009, p. 36).

The implementation of welfare policies at work, including the Health Support Services managed by BPD, were intended to integrate workers into factory life. By necessity they also needed to reproduce a context, somewhat similar to the real one, where women and the family symbolized everyday life. The harmonization of social life that revolved around the factory, itself the main source of income, the creation of a sense of belonging and solidarity were to ensure social peace and greater efficiency on the job. Employees were fully aware that the company supported them whenever needed, as was the case in 1938 when a fire destroyed the factory and there were several fatalities; BPD responded by quickly creating a shelter for the victims’ orphaned children (de Orleans-Borbon, 2011, p. 93).

²⁵ The Industrial Village in Colleferro, cit., pp. 12-19.

²⁶ ASCColleferro, BPD, M.a.o., *25 anni di vita della B. P. D.*, cit., p. 11.

The industrial village brought significant and positive effects to the area as well: many facilities in Colleferro (including schools, City Hall, the Fascist Hall, the Church of Saint Barbara, and various sports facilities) were designed by Riccardo Morandi, the same engineer who oversaw the expansion of the workers' village. This choice contributed to a form of aesthetic harmonization of the urban landscape. From a political point of view, increased economic activities and the growing numbers of the local population were decisive, leading to the town of Colleferro becoming a municipality in 1935 when it absorbed parts of the neighbouring areas belonging to the municipalities of Valmontone and Genazzano (Rome)²⁷.

Colleferro's identity was solidly entwined with its factories; it gained the moniker of "worker city" (Marcelli et al., 1983, p. 121). Company policies reverberated on the population as a whole, including even those who were not actually employed within the facilities. Via a sizable network of social relationships, BPD's managers intervened in civic life, placating social conflicts and implementing agreements that would have a positive effect on the community as a whole. For Parodi Delfino, Colleferro represented not only a great industrial project but, above all, a place where he and his employees could live happily.

9. BPD: women and employment in the Industry of explosives

BPD was especially interested in supporting its female employees, encouraging them in their professional training and assisting them with their family responsibilities by creating places for childcare that operated for both day and night shifts. Compared to their male counterparts, the women had more duties so BPD strived to involve them in those political and social activities deemed as valuable both for the nation as well as the public sphere.

The natural flexibility of its female workforce represented for BPD a "strategic" component in achieving market objectives. As most of the female workforce came from poor families and often with little formal education, a series of initiatives in favour of these women were introduced. BPD went on to support gender equality during the Fascist era.

²⁷ Law issued on 13 June 1935, no. 1147. *Gazzetta Ufficiale*, no. 157, 8 July 1935, pp. 3469-3470.

In particular, such elements became a reality thanks to some of the changes implemented by Parodi Delfino in the factory (Nardone, Ridolfi, Di Nucci, 2021).

Constantly monitored by the Fascist regime, BPD's manufacturing activities were deemed strategic in nature and necessitated an ever-growing workforce. Initially the Colleferro plant employed a highly specialized male workforce together with a growing number of engineers. By the second half of the 1920s, the company's needs had expanded to such a point that they needed to employ women as well. From 1925 onwards, when the Fascist policies became fully totalitarian, because of the significant increase in its activities²⁸ BPD achieved profits for a million lire notwithstanding the "Quota 90" revaluation of the lira and its economic effects. The company's needs were so urgent that management opened the factory doors to welcome female workers who then went on to become an integral part of the production system (Marcelli et al., 1983, p. 115). In the BPD plant in Colleferro, workers of both sexes found themselves "living together", and they felt a constant tension, something made more evident for the female workers forced to navigate between factory work and domestic responsibilities.²⁹ The recurring requests for more production resulted in a robust demand-- and supply-- of employees who initially came from the local community but eventually called for expanding into the national labor market (Nesti, 2012, pp. 158-160).

In a short period, the factory in Colleferro employed workers from all over Italy, extending from southern Italy all the way to some provinces in Northern Italy. The women who arrived "to work the new lands arising from the reclamation of the Pontine Marshes" were also involved in factory work (Marcelli et al., 1983, p. 134; de Orleans-Borbon, 2011, p. 79).

Full integration between male and female activities was thus achieved in the BPD factories. A favourable working environment, free of social constraints, was created, itself a sort of workshop to train tomorrow's workers.

On the factory floor, women were employed in divisions that required special skills and limited physical effort, performing activities like loading gunpowder into bullets or explosive devices.

Despite the severe effects of the great economic crisis and a factory blast that claimed the lives of five employees, in the 1930s BPD continued to

²⁸ ASCCIAARoma, *Bombrini Parodi Delfino*, envelope 86, file 15, volume I, Budget for 1927.

²⁹ ASCColleferro, BPD, M.a.o., *Il centro industriale*, MCMLI, s.p.

strengthen its productive assets while experimenting with diversified production. Between 1930 and 1931, it opened another ammunition factory in Colleferro that focused on small and medium calibres; the new factory also employed female workers. In the Thirties the company started producing cartridges for machine guns of various calibres. Some of them were completely new for the national market; they were produced together with the other kinds of ammunition needed for artillery and long-range projectiles used by the Italian Navy.

For these product lines the workforce was predominantly female. With their smaller hands, women were particularly skilful at inserting gunpowder into cartridges. These operations had to be carried out in an accurate and timely fashion, without wasting precious raw materials. Production rhythms went on to become very intense, often with shifts of eight, ten, even 12 hours (Marcelli et al., 1983, pp. 116; 136-138). The women were sometimes paid with piecework wages. Each employee had a productive minimum, usually about 2000 bullets per day, and there was an increase in wages for workers who exceeded these minimums. Greater production was rewarded by the same token, without any distinction of gender, sometimes generating challenges and discontent.

And I sent some money back home, since I gained more than all the other girls in the Colleferro factory, since I worked a lot. I produced more than all the other workers. I did not feel tired when I had to work. And I was swift, so swift that I produced double the amount compared with that of the other workers. And in the end, the others were also mad at me, since I was producing more than double the amount, compared to the others. Some jobs in the factory were piecework and others weren't³⁰.

During the Thirties, BPD expanded its production and involved female workers in all its shifts (Marcelli et al., 1983, pp. 116). From 1935 onwards, production in the facility (which had grown significantly due to orders by the State for the war efforts in Ethiopia³¹) called for a bigger workforce; this meant including more women.

Managing such a large number of workers meant that the company needed to implement greater protections and safety measures and establish internal regulations without gender distinctions. Regulations called on employees to

³⁰ National Journal Archive in Arezzo (ADNA, from its Italian acronym), *Diario di Adelia Trivellato*, c. 12.

³¹ ASCCIAARoma, *Bombrini Parodi Delfino*, envelope 86, file 15, vol. III, Budget for 1937.

have “a sense of duty and discipline”, commented on appropriate work attire for everything from jumpers to hairnets, and established rules for the use of restrooms and the like. Failure to comply with the rules would lead to reprimands and terminations (Marcelli et al., 1983, pp. 136). The solidarity BPD created with its female workers could also be seen in the creation of women-oriented buildings constructed in the industrial village including a facility that housed single female workers who hailed from afar and needed lodging³².

BPD provided an important contribution to Italy’s military policies (as unrealistic as they were) and soon achieved market leadership in explosives³³. BPD also had a good presence in international markets, exporting to Albania, Bulgaria, Romania, Yugoslavia, Spain and France (the latter used them in North Africa)³⁴. Production expanded so much that in 1936 the company achieved a profit of 6 million lire on revenues of more than 18 million³⁵.

This pattern of growth meant that from 1925 onwards, BPD hired an additional 600 women (on top of those who were already employed). It was then that the company decided to finance the construction of an additional “boarding structure for female workers of the company” (Mazzocchi, 1980, p. 90). Management of the house was entrusted to a religious order that looked after the girls full time. The nuns prepared the meals, organized the cleaning and accompanied the younger female workers to their workplace. Of course, there were moments dedicated to prayer and religious celebrations but there was time for recreational activities as well³⁶.

³² Il Villaggio Moderno Industriale di Colferro, cit., p. 13.

³³ ASCColferro, BPD, M.a.o., *Libro inventari*, 1924-1936. The following companies were supplied: Industrie Meridionali Miniere Zolfo – Benevento; Società Solfiture Siciliana – Catania; Impresa Condotta Agricola – Cortona; Imprese Lavori Pubblici – Genoa; Idroelettrica Alto Lascio - Mercato Saraceno; Fabbrica Accessori Tessili – Monza; Di Pietra Vincenzo – Palermo; Ferrovie dello Stato – Porretta; Ministero Lavori Pubblici – Rome; Società Romana Costruzioni Meccaniche – Rome; Ferrovie Settentrionali Sarde – Sassari; Strade Ferrate Pugliesi – Taranto; Imprese Palagiano – Taranto; Fabbriche Riunite Cemento – Trento; Industrie Marmi Vicentine – Vicenza; Imprese Minerarie Trentine – Vipiteno.

³⁴ BPD, M.a.o., *Libro inventari*; 22 September 2021 interview with Renzo Rossi, in charge of the Historical Archive of the Documentation Center of the Municipality of Colferro (Rome, Italy). The exports were directed as follows: Romania’s Ministry of War – Bucharest; the Bulgarian Government; the government in Nanking (China); the company belonging to Mr. Mazorana – Tirana; Kanieti André – Durazzo; Shuka – Valona; Ministry of Public Works – Tirana; Anti-Malaria Department – Tirana; “Dinamite” company – Zagreb.

³⁵ ASCCIAARoma, *Bombrini Parodi Delfino*, b. 86, file 15, vol. III, Budget for 1937.

³⁶ ADNA, *Journal*, cit., c. 14.

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The boarding structure became an important addition to the village which, in the meantime, had grown to include other recreational facilities such as cinemas, theatres, restaurants and bars³⁷. BPD also purchased some nearby agricultural lands, making them available to the workers' families for the cultivation of gardens (Bombrini Parodi Delfino Company, 1927, pp. 24-31).

In 1938, as the Italian government set its sights on rearming the nation and production at BPD achieved "its highest degree of efficiency"³⁸ (being able to count on more than 8200 employees³⁹) the factory was devastated by a second explosion that killed 60, wounded many and caused significant damage, even destroying some nearby houses. However, the incident did not stop production and Bombrini Parodi Delfino quickly started back up, increasing the social activities of the company with a series of initiatives aimed at supporting the employees, as well as the widows and the orphaned children. The company managed the reconstruction efforts directly and even refused the State's offer of a contribution of about 40 million lire to carry out the entirety of the operations in the best possible way and in a short period⁴⁰.

10. Final considerations

Our analysis of female employment has focused on the Fascist era, when the political, cultural and religious climate joined forces to discourage women from working outside their homes and, even more so, in the explosives sector as this was historically --and perhaps also physiologically-- the province of males. For these reasons, the managerial actions of Leopoldo Parodi Delfino can be seen as those of an "enlightened" and realistic entrepreneur. He combined a modern vision of the management of human capital and, by his actions, made a significant contribution to progress towards gender equality.

Of course, being born in northern Italy, pursuing university studies in Switzerland and then some early experiences working in Germany gave him contacts with environments that were already dealing with the first ferments of the movement towards the emancipation of women⁴¹, both politically and

³⁷ Il Villaggio Moderno Industriale di Colleferro, pp. 12-19.

³⁸ ASCColleferro, BPD, M.a.o., *Il centro industriale di Colleferro*, s.p.

³⁹ ASCColleferro, BPD, M.a.o., *Ufficio mano d'opera. Alcune considerazioni quantitative sul personale dell'ufficio mano d'opera*, 1938.

⁴⁰ ASSR, Ufficio di segreteria, cit., p. 27.

⁴¹ The International Women's Association was established in Switzerland in 1868. Its main goal is to achieve legal gender equality (Bianchi, 2015, p. 10). In 1872, Marie Goegg-Pouchoulin, the Association's founder

socially. They were experiences that undoubtedly shaped his vision of women in the workplace. His background made it easier to seriously consider the new vision of enterprise management based on welfare policies that were sometimes shaped by specific circumstances yet remained in line with the Fascist government's final goal of social control.

The integration of female employees within his largest industrial project, BPD, provided the solution to growing production needs and a shortage of male workers. What made the BPD experience especially noteworthy was the company's understanding of the needs and potential of working women without considering them as a lesser copy of male workers (Meldini, 1975, p. 37). At the end of the day, Parodi Delfino turned the necessity of employing women in his factories into an opportunity. Aware that the necessary actions involved in re-arming Italy offered a great business opportunity, Parodi Delfino grabbed the chance, ending up as both a technological and a social innovator.

Still, Leopoldo Parodi Delfino was by no means a magnanimous boss. "Women were sent whenever needed" and, as stated by an observer of the times, "women did not work for fun [...] but rather out of need" (Argo, 1933, p. 267). Still, given the longevity of the enterprise, for Parodi Delfino this entrepreneurial model worked.

In 1924 Carlo Bombrini died. Parodi Delfino acquired his shares, becoming the sole shareholder. Parodi Delfino survived his own two sons when they died in a plane crash in 1936 and continued to manage the company until his death in 1945. By the time of his death, BPD had absorbed Cementi Segni and counted on the collaboration of thirty thousand employees. In 1968 it was incorporated into SNIA (a world leader in the production of artificial silk), becoming SNIA BPD⁴². Five years later, Parodi Delfino's heirs sold their shares in the company, effectively marking the end of an entrepreneurial adventure that had lasted for 61 years.

achieved the admission of women at the University of Geneva and, two years later, she secured the abolishment of male tutelage on the assets of unmarried and widowed women in the canton of Vaud (Chaponnière-Chaix, "Une Pionnière," 139-146). In Germany, the Weimar Republic had bestowed voting rights on women. During World War I, because of war-related needs, women had entered the workplace. By the end of the conflict, about 11 million of them had long-term employment (Aspmair, 1982, pp. 198-235).

⁴² The Società di Navigazione Italo-Americana (SNIA, from its Italian acronym), was established on 18 July 1917 in Turin. Snia BPD spa, Company Register Number: 126534 Mi (1917), Historical Archives, Lombardy Region, Cultural Heritage.

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As a curious aside, in the years after Leopoldo Parodi Delfino's death, BPD was the training ground of two managers who left an important mark on Italian capitalism. Both Mario Schimberni, who would later go on to serve as president of the chemical giant, Montedison, and Cesare Romiti, who would take on the role of CEO at Fiat, started their professional careers at BPD in 1947. Even if they were colleagues and good friends at BPD, in the final years of the 21st century they fought acrimoniously for big business supremacy in Italy. We have no record of their ideas regarding women in the workplace; clearly this could be the focus of another essay in the future.

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CAN DIFFERENT LEARNING PATHS PRODUCE BETTER
ESTIMATES IN EMPIRICAL ASSET PRICING VIA MACHINE
LEARNING?

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Abstract.

This paper demonstrates how a portfolio composition technique can leverage the power of machine learning approaches in empirical asset pricing, using a very large set of identical Neural Networks (NN) and differentiating them only by the initial set of parameters. We implement the portfolio employing a trivial rule of ensemble, demonstrating how the variety generated by the initial conditions of the Neural Networks can produce better results than the average. This approach shed a new light on the potential application of ensemble methods to outperform a single NN involved in portfolio construction strategies, using more complex rules to extract the information discovered by the different training paths of identical NN.

JEL CODES: C45; G12; G17

KEYWORDS: EMPIRICAL ASSET PRICING; MACHINE LEARNING;
PORTFOLIO CONSTRUCTION

1. Introduction

In this paper we outline the methodology that guides the portfolio management process at Qi4M. We perform the analysis focusing on the

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problem of predicting expected returns. As a result, we obtain a model further used to develop an investment strategy that selects the equities to be included in a periodic portfolio. Using an ensemble rule, different from the commonly used average, for combining K estimates further contributes to better prediction and, subsequently, to the selection of best performing stocks. We then present the reader with experimental analysis, which is supported by historical pro-forma results.

When it comes to asset pricing research, one can evidence the extensive application of machine learning methods. For instance, time series asset pricing theory revolves around the ability to explain a satisfactory level of variability in a stock's future returns. This is a fundamental problem of prediction that in large has always been characterized by the ability of a researcher to select the most relevant predictors for a specific asset or time period that is being subject to analysis. In the previous work we showed in which way machine learning provides an optimal solution to this problem. Some important aspects of machine learning have been described as the ability to connect linear to nonlinear models through set functions, or to provide a high level of control in avoiding over-fit bias and false discovery.

The main characteristic of machine learning is that the rules governing the algorithms' functioning do not need to be explicitly coded. The model discovers rules on its own, looking at the *training set*, to then generalize the rule that will later drive its output construction. We showed how the adoption of two different *training* methodologies, supported by the creation of two different *training sets*, can significantly contribute to building performing portfolios.

Using machine learning and neural networks in particular, one inevitably encounters the problem of managing the randomness of results. Training algorithms for deep learning models are usually iterative in nature and thus require the user to specify some initial point from which to begin the iterations. Moreover, training deep models is a sufficiently difficult task that most algorithms are strongly affected by the choice of initialization. This makes the neural network unstable and unreliable, especially when sharing your code with others or showcasing your work (Zhuang et al., 2021). When looking at portfolio selection, we can potentially have different portfolios, as performances differ each time the algorithm is run. Randomness can occur in NN due to multiple reasons. Here we refer to random initialization of weights, biases and batch sampling. The literature suggests that random seeds can adversely affect the consistency of models

resulting in counterfactual interpretations, when randomness is not managed.

Most of the authors who have raised the question of the application of machine learning in asset pricing have overlooked, or avoided, this point.

Random noise is crucial for getting NNs to work well: it allows neural nets to produce multiple outputs given the same instance of input and limits the amount of information flowing through the network, forcing the network to learn meaningful representations of data. Therefore, the characteristic randomness of the NNs can be used as a resource to improve the final prediction. Usually, in financial environment we want to achieve the model's stability, specifically volatility and returns that are stable overtime. We want to demonstrate how achieving the stability of the model using N different neural networks can actually lead to better portfolio selection. We will compare the standard average method on predictions with a single model, and another, less trivial ensemble rule of N neural networks.

2. Methodology

We begin by defining an investment universe that makes up the model's input. We consider highly liquid stocks that would allow us to interact on the market without price or volume frictions. As previously stated, the initial input selection of the model has been influenced by an arbitrary selection on our part, which is a product of conjunct research efforts. We will keep the description of such selection terse. The reader can refer to the previous work for details.

From this step, the model undergoes the training and testing phases, employing methodologies that will be presented in this section. The next step is to manage a basket of NN models with an ensemble, which is a product of 200 random seeds. The ultimate output of the model is an investment strategy in the form of a portfolio of equities, which repeatedly over-performs the universe's benchmark.

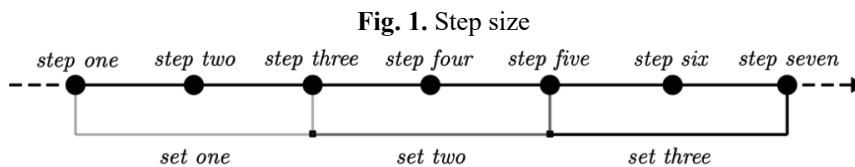
We will follow with a description of the financial theory that influenced the construction of the model, avoiding to present the reader with a profound description of the relevant models. We invite the reader to refer back to the bibliography, to gain a more thorough understanding of the topics mentioned in the discussion.

2.1 Prediction

The preliminary step in the formulation of our approach is to understand how to best design sub-samples for estimation and testing¹. This process starts from setting a time-frame for the characteristic *walk-forward* we employ for training and testing both models.

The two methodologies cited before refer to two different methods we apply to perform the *walk-forward*. We essentially define the *steps* that constitute the *walk-forward*. Here, *steps* indicate the event of new information becoming available to the market. In our case, the *steps* indicate the update of a given company's set of selected fundamentals. With respect to the aforementioned *steps*, we can differentiate the two methods that from now on will be referred to as 'Veloce' and 'Lento'. We then use this set to predict stocks' returns at a future point in time.

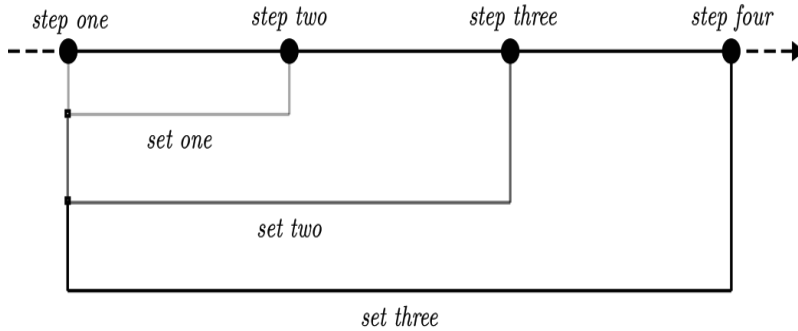
The first method, 'Veloce', creates a fixed *steps-size* train set using the last 'few' n *steps* available in the information set. Once new information becomes available, it moves the rolling window forward to create a new train set that drops the first *step* and picks up the last. The number of steps chosen for the 'Veloce' method is $n = 5$ for our experiments. On the other hand, the second method, 'Lento', updates the training set by increasing its size to include new information available at the new *step*.



The figure shows a fixed-length step in time. In this example the step length has been fixed to $n = 2$.

¹ Note that when constructing the *training set and test set*, one incurs two phenomena: missing data and noisy data. To overcome the problem of missing data, we apply the method suggested by Beaver et al. [2007]. At the same time, we adopt the approach proposed by Steege et al. [2012] to handle the noisy data.

Fig. 2. Step Incremental



To perform the prediction of stock returns we adopt two regressors: a feed- forward multi-layer perceptron (MLP), and a multivariate linear regressor(LR), which are then used to minimize the same objective function, the mean squared prediction errors (MSE). The multi-layer perceptron’s training phase handles the dynamics to be picked up by the ‘Lento’ method, while those of ‘Veloce’ are better handled by the multivariate linear regressor. For the ‘Lento’ model, we train K MLPs that differ in initialization of weights and biases. So in the end we will have K + 1 signals (predictions), where K is the result of the ‘Lento’ approach and one of the ‘Veloce’ model.

The ‘Lento’ model gives us the following output:

$$L = (l_{t,k}^s)_{s,t,k} \tag{1}$$

indexed by:

$\forall t = 1, \dots, T$ rebalancing date,

$\forall s = 1, \dots, S$ stock in universe,

$\forall k = 1, \dots, K$ random initialization of MLP,

where $l(s, t, k) \in R$

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While, from the 'Veloce' model we get the following array of signals:

$$V = (v_t^s)_{s,t} \quad (2)$$

$\forall t = 1, \dots, T$ rebalancing date

$\forall s = 1, \dots, S$ stock in universe

By rebalancing date we mean the date on which training is performed with the walk-forward method described above, also intended as the step in defining training and test set. Therefore, at each rebalancing date we will have an out- of-sample prediction that corresponds with the next training step.

2.2 Ensemble

In this section we show how the 'Lento' and 'Veloce' output can be combined to build the ensemble rules (i.e. scores) that will guide the portfolio selection. We will specifically show two rules that differ in the use of the 'Lento' model. The first trivial one involves the average of the k scores of the 'Lento' model. The second one uses each score of the 'Lento' model as a market view in its own right.

Mean ensemble Whenever we employ a model whose result depends on the initial conditions, it is a good practice to train the model to vary the initialization parameter and then use the average of all the obtained results. This is the case with our 'Lento' model: it is constituted, in any given t and for each stock s , by k prediction scores (also known as k forecasting), one for each model initialization. The following equation illustrates how the array of signals is built:

$$L' = \left(\frac{1}{K} \sum_{k=1}^n (l_{t,k}^s)_{s,t,k} \right)_{s,t} = (l_t^s)_{s,t} \quad (3)$$

We subsequently build the final score by defining:

$$R = \min(L', V) = (\min(l_t^s, v_t^s))_{s,t} = (r_t^s)_{s,t} \quad (4)$$

The parameters we refer to, are defined as follows:

$K = 200$ random seeds,

$T = 42^2$ quarters,

$S = 980^{63}$ stocks on average.

The final portfolio is constructed using this rule, which means that for each t we take the first 30 stocks, sorted by the r score in a descending order.

Union ensemble Since we operate in the context of financial environment, different results produced by K NN be interpreted as different market views, instead of making an average prediction.

For each fixed initialization k we construct the vector:

$$R_k = \left(\min(l_{t,k}^S, v_t^S) \right)_{s,t,k} = (r_{t,k}^S)_{s,t,k} \quad (5)$$

From now on, we will refer to R_k with its descending enumeration i.e. the ranking. Using the series $(R_k)_{k=1,2,\dots,K}$, that are K ordered lists of stocks at every fixed rebalancing date t , we want to construct a portfolio with at least P ($P = 20$) stocks, that are in the top of the ranking. We do this using the algorithm described in the following pseudo code that will run for every fixed rebalancing date t .

² The quantity of quarters (training steps) on which experimentation is carried out. The period under examination contains almost 11 years, i.e 42 quarters

³ The number of stocks that make up the universe in each quarter (i.e. in each step, i.e. in each rebalancing date). It is a variable number, since it depends on the actual availability of the stock traded on market at each point of time.

Can different learning paths produce better estimates in empirical asset pricing via machine learning?

Algorithmus 1 Unio
Input: P is the minimum stocks in the selected portfolio, L is the number of stocks in the current portfolio, S the number of stocks in the universe, r' a parameter that represents a guide to select the stocks over the ranking
Output: Portfolio Initialize: $r' = 1, L = 0$ while $L < P$ or $r > S$ do <i>current portfolio</i> = $\{s \in universe : s \in U_{k=1}^K \{r_{s,t,k} \in R_k : r_{s,t,k} \leq r'\}\}$ $r' = r' + 1$ end while

In other words, for every fixed rebalancing date t we make a union of K ordered lists of stocks that are at least in the top 20⁴ positions of the ranking.

3. Experimental evaluation

In this section we summarize our findings about different ensemble methods, constructed over $K=200$ runs of the model, with 200 different random seeds, and with identical model settings. We report ensemble performances in terms of financial indicators.

The first graph (Fig.3) represents the level of variability of performance as the random seed changes. By choosing one seed instead of another, we will potentially have very different portfolios, which makes the results of the model difficult to interpret. We also see how the two ensembles, mean and union, are placed in the sparsity of results. The mean ensemble helps produce the final result in a very trivial way and is a satisfactory solution for achieving the stability goal. Yet, as we can observe, it is not the best solution, unlike the union, which doesn't only solve the problem of randomness but also has a positive effect on the return and Sharpe ratio.

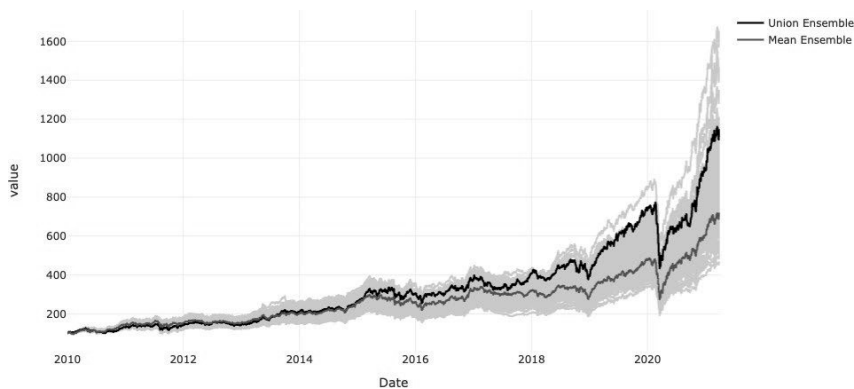
⁴ To make the portfolio construction strategies, and the portfolios themselves, comparable, they must be composed, on average, of the same number of stocks. So:

- For the Mean ensemble, on each rebalancing date we take the first 30 stocks, thus obtaining a portfolio consisting of exactly 30 stocks in each quarter;

-For the Union ensemble rule we set the minimum number of stocks for each of the K ($K = 200$ random seeds) models at 20. By definition, portfolios are built as a union of models, so that the final number in each quarter will be, on average, around 30.

Table 1. Out-of-sample financial performance

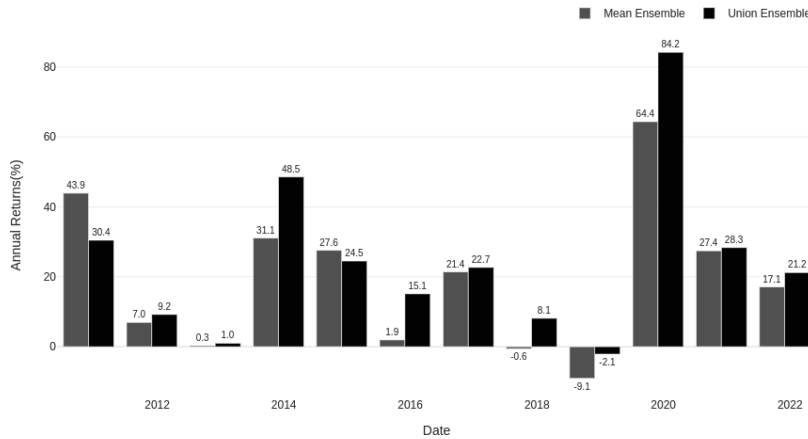
	<i>Mean Ensemble</i>	<i>Union Ensemble</i>
Return	19.01%	24.13%
Volatility	19.16%	20.84%
Sharpe Ratio	0.99	1.16
Max Draw-down	-43.99%	-43.72%

Fig. 3. NAV.

The figure shows performance in terms of cumulative product of investment of 1Euro from 2010 to 2021, of $K=200$ runs of the model with 200 different random seeds. In addition, mean and union ensembles are shown for comparison.

We noticed that in 5% of the cases, some of the random seeds exhibit, on average, better performance than the union ensemble. While it is true that some random seeds (in the long term) perform better, it is equally true that there is a priori no way to identify these random seeds. Since the random seed is usually not a tuning parameter, the goal of this study is to show the reader that there is a method that produces better performance than the usual mean ensemble.

Fig. 4. Annual returns



The figure shows performance in terms of percentage annual returns from 2010 to 2021. The graph compares a single random seed model and the mean ensemble to the union ensemble, whose performance is significantly better during the time of the investment.

4. Conclusion

In this article, we study how the inherent instability of neural models as a function of random seed can actually be used as a resource in the selection of portfolios in the field of machine learning.

We analyze the performance and robustness of the model in the form of financial performance. Our analysis strongly highlights how model stability problems and its effects on black box interpretation methods lead to different views of the financial market for different random seeds, and the ways they can be exploited to our advantage.

Only by varying the random seed and keeping all the parameters unchanged we introduce the variability necessary to make an ensemble of the predictors and with this obtain the possibility to significantly improve the performance of the final model.

We have proposed two solutions to overcome the problem of randomness. The first is the trivial rule of averaging, while the second one, the union ensemble, is more performing and brings added value to our final portfolio selection. We prove that our proposed method is significantly more efficient

than using a single initialization or an average model, and greatly reduces the model's instability and increases the performance.

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NEXUS BETWEEN INTELLECTUAL CAPITAL AND PERFORMANCE OF COMMERCIAL BANKS

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Abstract

The significance of Intellectual Capital (IC) is paramount, as it is seen as a necessary asset for the success of high-tech organizations such as banks. Therefore, it is essential to focus on the understanding and implementation of IC in the context of commercial banks. The primary objective of this study is to investigate the influence of intellectual capital (IC) on the financial and non-financial performance of commercial banks that are listed on the Karachi Stock Exchange (KSE) within the time frame spanning from 2010 to 2020. The intellectual capital of a corporation was determined using the Value-Added Intellectual Coefficient (VAICTM) approach. The study of panel data included the use of fixed effect and random effect regression models to investigate the relationship between components of intellectual capital (IC) and company performance. The empirical study's results suggest that there is a stronger correlation between structural capital efficiency and company success compared to capital employed efficiency and human capital efficiency. There exists a positive correlation between the Value-Added Intellectual Coefficient (VAIC) and both financial success and market performance. However, a negative correlation is shown between VAIC and

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customer satisfaction. Based on the results of recent research, commercial banks in Pakistan should prioritize the development of their intellectual capital in order to reap advantages and establish themselves as a benchmark for other industries.

JEL CODE: G21; M12; M14; O34; L25

KEYWORDS: INTELLECTUAL CAPITAL, RETURN ON ASSETS, CAPITAL EMPLOYED, RETURN ON EQUITY, STRUCTURAL CAPITAL

1. Introduction

In the present economic climate, the prosperity of a firm hinges upon its ability to identify the specific skills and competencies necessary for its operations, as well as the strategic use of these talents to attain a competitive edge within the industry. According to Khalique, Shaari, and Isa (2013). Organizations are engaged in a competitive endeavor to maintain their competitive advantage via the use of their distinct and exclusive information (Grant, 1996; Prusak, 2001). Knowledge is a valuable strategic asset for firms in order to achieve advantages and is also considered one of the crucial resources for organizations (Khalique, Shaari, & Isa, 2013).

Knowledge-based assets have been identified as the primary drivers of an organization's competitive advantage (Ting & Lean, 2009). On the contrary, Khalique, Isa, and Shaari (2011b) posited that in a knowledge-based economy, the inclusion of values in intellectual capital (IC) has become more crucial compared to physical resources. Information and Communication (IC) has a significant role in fostering organizational development, surpassing the contributions of other sources (Foray, 2004). In the contemporary landscape of competitive markets, the establishment of high-tech firms mostly relies on the use of intellectual capital, which encompasses valuable knowledge-based resources. (Khalique, Shaari, Md.Isa, & Samad, 2013) conducted a study.

In order to enhance comprehension of intellectual capital, scholars have categorized it into many components. Edvinsson (1997) proposed a classification of intellectual capital consisting of two components: structural capital and human capital. Stewart (1997) expanded the categorization of the distribution into three components: customer capital, people capital, and

structural capital. However, Brooking (1996), Bontis (1998), and Kujansivu (2009) argue that intellectual capital is not just based on three factors, but also encompasses additional intangible resources like as skills, brand name, organizational structure, knowledge, customer relationships, and staff competency. In 2005, Ismail introduced the concept of "spiritual capital" as a component that contributes to the integration of intellectual capital. Intellectual capital refers to a composite entity including human capital, customer capital, and structural capital. According to Riahi-Belkaoui (2003), The banking business has emerged as a sector that requires a high level of expertise in a rapidly changing and competitive environment (Mavridis, 2004). In order for knowledge-intensive firms to establish dominance in the financial sector, it is essential for them to effectively use their resources, with a particular emphasis on intellectual capital (Khaliq M., Shaari, Md. Isa, & Samad, 2013). The banking industry is a suitable candidate for doing research on the issue of intellectual capital due to its high level of knowledge intensity and the intellectual capacity of its whole workforce (Mavridis, 2004).

2. Literature Review

Following the advent of the industrial revolution, there has been a shift in societal focus from physical labor to intellectual capacity, which is widely seen as a crucial determinant in economic activities (Goh, 2005). The existing system is influenced by a combination of specialist knowledge, technology, and relationships with many stakeholders, together referred to as intellectual capital (Ahangar, 2011).

3. Intellectual Capital

The inception of the notion of intellectual capital may be attributed to John Kenneth Galbraith, who first articulated it in 1969. The topic in question gained significant attention after its popularization by Tom Stewart in 1991, with the publication of his article titled "Brain power: How intellectual capital is becoming America's most valuable assets" in Fortune Magazine. According to Kalkan, Bozkurt, and Arman (2014), According to Stewart (1997), intellectual capital may be succinctly defined as "packaged useful knowledge." The term "intellectual capital" is sometimes referred to as "know-how capital," including both individual and structural capital. Individual

capital refers to the cumulative personal attributes possessed by an individual, including their knowledge, experience, skills, social talents, and professional capabilities. On the other side, structural capital pertains to the collective competencies of an organization, encompassing its historical background, systems, software, handbooks, accumulated experience, and computer programs. According to Sveiby (1989),

According to Edvinsson and Malone (1997), intellectual capital (IC) refers to knowledge that has the potential to be transformed into value. The achievement of a company is contingent upon the adept and efficient use of its intellectual capital within a competitive milieu. (Porter, 1999).

4. Human Capital

In the context of the knowledge economy, it is undeniable that human capital has significant value. Human capital is a significant contributor to the creation of value inside a business. According to Fitz-enz (2000), the foundation of this concept is in the acquisition of information, development of professional skills, demonstration of competence, cultivation of a positive attitude, and use of intellectual talents. According to Wright, McMahan, and McWilliams (1994), the resource-based view posits that human capital serves as a foundation for attaining a sustained competitive advantage. In their study, Seleim, Ashour, and Bontis (2007) examined the relationship between human capital and business performance within the context of software firms. Their findings indicated a statistically significant positive link between these two variables.

5. Structural Capital

The role of structure capital is also a crucial element within the realm of intellectual capital. This encompasses all elements that are not of a human nature, such as regularized activities, mathematical equations, established guidelines, operational protocols, competitive dynamics, and databases (Khalique, Shaari, Md. Isa, & Ageel, 2011d). Rehman, Asghar, and Rehman (2013) identified structural capital as a category of non-human assets that include many elements like as processes, rules, databases, procedures, patents, copyrights, and trademarks.

According to Goh (2005), structural capital refers to the knowledge possessed by a company that persists inside the organization even when personnel are absent from the premises. The aforementioned citation by Bontis (1998) posits that this procedure serves to aid workers in their tasks, hence augmenting their performance and bolstering overall corporate productivity.

Carbrita and Vaz (2006) assert that strategic capabilities (SC) pertain to an organization's capacity to effectively address both internal and external problems.

6. Capital Employed

The inclusion of capital employed is a significant factor within the framework of intellectual capital. Capital employed is sometimes referred to as "customer capital," "relational capital," and "external capital" in academic literature. According to Bontis (2002), the measurement of capital employed may be influenced by the concept of longevity. Additionally, the marketing literature has posited that establishing enduring associations might serve as a means of attaining a competitive advantage. The augmentation of capital employed may be achieved via the enhancement of both human capital and structural capital. According to Pouraghajan, Ramezani, and Mohammadzadeh (2013), capital employed plays a significant role in the transformation of intellectual capital into market value.

7. Market Performance

The market value of a corporation ultimately reflects the total worth of its net assets. Companies that effectively communicate the significant worth of their intangible assets are likely to get a favorable reaction from the market. According to the study conducted by Fourati and Affes in 2013, it was found that... The growth in the value of intangible assets leads to an increase in the market value of a corporation. (Low, 2000). The market value of a business's share, in comparison to the book value of the firm, is used as a proxy measure for the market value of the firm.

8. Business Performance

The assessment of company performance has significant importance for organizations. Various market, accounting, and financial indicators are used to assess the profitability, productivity, and market performance assessment of businesses. Chu, Chan, and Yu (2011) conducted a study to investigate the relationship between intellectual capital (IC) and company success. The researchers used three proxies, namely assets turnover (ATO), return on assets (ROA), and market to book ratio (M/B), to assess the business performance. According to the definition provided by Zack, McKeen, & Singh (2009), business performance measurements include several perspectives, including customer happiness, rate of new product innovation, and customer retention. Financial indicators are considered the most limited approach for assessing organizational performance, whereas indicators of operational success are seen as a more comprehensive method for evaluating organizational performance (Schendel and Hofer 1979).

9. Intellectual Capital and Business Performance

In his comprehensive analysis, Sveiby (2010) critically examines a total of 34 methodologies used for the purpose of quantifying Intellectual Capital (IC). Among the several approaches available, the VAICTM (Value Added Intellectual Coefficient) method is considered the most extensively used and recommended approach for accurately assessing the performance of intellectual capital (IC). The VAICTM approach quantifies the extent to which new value has been generated as a result of each monetary unit of resources spent. A high coefficient indicates a significant level of value generation via the use of organizational resources. The study conducted by Ahangar (2011) examined the impact of information communication (IC) on the financial performance of the financial sectors in Iran, specifically focusing on profitability, sales growth, and staff productivity. The present study's analysis demonstrates that information capital (IC) has a major impact on both the profitability and productivity of firms. Additionally, it elucidates that human capital (HC) has a direct association with corporate performance.

In research conducted by Sharabati (2010), the impact of intellectual capital on the success of pharmaceutical businesses in Jordan was analyzed. The findings of the study revealed a favorable correlation between intellectual capital and economic performance. In their study, Muhammad and Ismail

(2009) performed a survey focusing on the banking industry in Malaysia. The findings of the research indicate a favorable correlation between intellectual capital (IC) and corporate success. However, it is noteworthy that the level of IC was found to be somewhat lower in the banking sector compared to the insurance and brokerage industries. It has been concluded that in Malaysia, the determination of market value is based on the capital utilized rather than the concept of CI (Capital Intensity). Utilizing a comprehensive dataset spanning a five-year period from 2001 to 2005, including firms listed on the Hang Seng stock exchanges. In a study conducted by Chan (2009), the researcher examined the relationship between the efficiency of intellectual capital (IC) and its many components in relation to company performance. The performance indicators considered in this study were return on assets, productivity, return on equity, and market value. The findings of the study demonstrated that the only factor contributing to the profitability of a corporation is its structural capital. In their research, Young, Su, Fang, & Fang (2009) examined a sample of Asian banks from eight countries and posited that the primary drivers of value creation in these banks are human capital and physical capital.

Daryae, Pakdel, Easapour, and Khalafu (2011) posited that there is no significant correlation between intellectual capital and return on assets. However, when corporate value is assessed using Tobin's Q, a positive link is seen between intellectual capital and corporate value. Bontis, Chua, and Richardson (2000) conducted research to investigate the interaction between the three components of intellectual capital. Their findings indicated that human capital and customer capital play significant roles in the functioning of a firm, while structural capital has a beneficial impact on corporate performance. In their study, Cabrita and Bontis (2008) performed research within the Portuguese banking setting to examine the interrelationships and interactions among the components of Intellectual Capital (IC) and organizational performance. Their findings indicate a positive association between IC components and business performance. The study conducted by Norma and McGee (2006) examined the relationship between intellectual capital and the performance of new ventures. Research was done on high-tech ventures businesses in the United States, and the findings indicate that human capital is a critical factor in assessing operational effectiveness. In a study conducted by Ranjith Appuhami (2007), a positive correlation was seen between capital gain and the proportion of investors.

The research done by Tan, Plowman, and Hancock (2007) included an analysis of 150 enterprises that were listed on the stock market in Singapore. The researchers conducted an observation and found a positive association between intellectual capital (IC) and several financial metrics, such as return on equity, profits per share, and annual share returns. Utilizing a comprehensive dataset over the timeframe of three years, namely from 2005 to 2007, including a total of 11 banks that are held by Australian entities. In their study, Joshi, Cahill, and Sidhu (2010) examined the impact of the VAICTM on business performance. The results revealed a substantial association between HCE and the financial success of companies. In contrast, the study found that SCE and CEE did not have the same level of influence on increasing bank performance. Similar research was undertaken in the insurance industry of Pakistan by Rehman, Ilyas, and Rehman (2011). Additionally, Chu, Chan, and Yu (2011) conducted an inquiry into the relationship between intellectual capital (IC) and market performance on the Hong Kong Stock Exchange. The study's findings indicated a substantial negative association between HCE and market performance. In 2003, Firer and Williams did a study to investigate the link between intellectual capital (IC) and market-to-book (M/B) ratio in African-based firms. The findings of their research indicated that there was no significant correlation between intellectual capital and market value.

Zehri, Abdelbaki, and Bouabdellah (2012) performed a study in Tunisia to examine the correlation between intellectual capital and company success. The study determined that there is a direct correlation between financial and economic success and intellectual capital. However, the study did not find sufficient evidence to demonstrate a direct association between market performance and intellectual capital. In their study, Kehelwalatenna and Gunaratne (2010) undertook research with the objective of assessing intellectual capital. They analyzed firm performance by considering return on equity and holding term return, while investor reaction was evaluated via the market-to-book ratio. The findings of the research indicate a strong correlation between intellectual capital and both investor reaction and business success across several industries. According to Maditinos, Chatzoudes, Tsairidis, and Thetiou (2011), there exists a negative but substantial association between SCE and M/B ratio. Additionally, HCE demonstrates a positive and significant relationship with market performance. According to Puntillo (2009), there is a positive correlation between capital employed and return on assets (ROA), indicating that an increase in capital employed is connected

with higher ROA. Conversely, there is a strong negative relationship between capital employed and the market-to-book (M/B) ratio, suggesting that an increase in capital employed is linked to a decrease in the M/B ratio.

10. Research Gap

There is a scarcity of research conducted in Pakistan that examines the relationship between intellectual capital (IC) and corporate performance. Intellectual capital is intricately linked to several stakeholders, including shareholders, managers, researchers, and those responsible for performance outcomes. This study uncovers the impact of information cascades in the long term. The present research aims to assess the relationship between intellectual capital and business success within the banking sector of Pakistan. The findings of this study may be used by managers to evaluate their own performance and serve as a benchmark for comparison.

11. Hypotheses

H₁: There is a positive relationship between human capital efficiency and return on equity

H₂: There is a positive relationship between structural capital efficiency and return on equity

H₃: There is a positive relationship between capital employed efficiency and return on equity

H₄: There is a positive relationship between human capital efficiency and return on assets

H₅: There is a positive relationship between structural capital efficiency and return on assets

H₆: There is a positive relationship between capital employed efficiency and return on assets.

H₇: There is a positive relationship between human capital efficiency and earning per share

H₈: There is a positive relationship between structural capital efficiency and earning per share

H₉: There is a positive relationship between capital employed efficiency and return on earning per share.

Nexus between intellectual capital and performance of commercial banks

H₁₀: There is a positive relationship between human capital efficiency and Market Performance

H₁₁: There is a positive relationship between structural capital efficiency and market performance.

H₁₂: There is a positive relationship between capital employed efficiency and market performance.

H₁₃: There is a positive relationship between human capital efficiency and customer satisfaction

H₁₄: There is a positive relationship between structural capital efficiency and customer satisfaction.

H₁₅: There is a positive relationship between Capital employed efficiency and customer satisfaction.

H₁₆: There is a positive relationship between intellectual capital and return on equity.

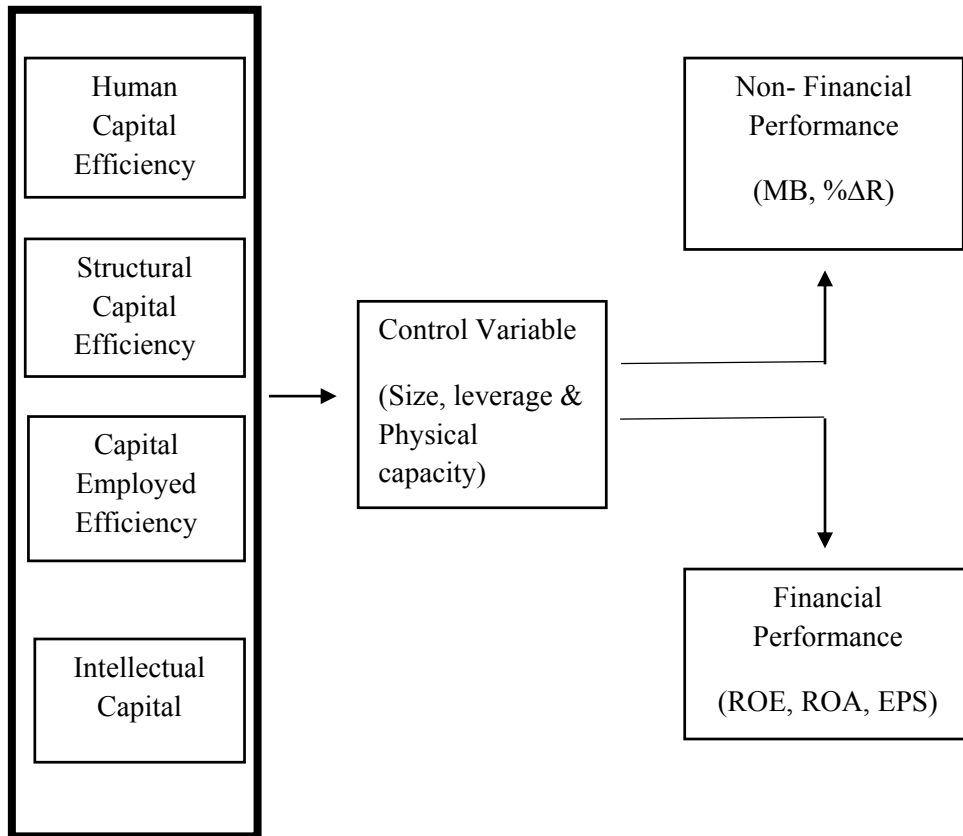
H₁₇: There is a positive relationship between intellectual capital and return on assets.

H₁₈: There is a positive relationship between intellectual capital and earning per share.

H₁₉: There is a positive relationship between intellectual capital and market performance

H₂₀: There is a positive relationship between intellectual capital and customer satisfaction.

Conceptual Framework:



12. Research Methodology

Population/Sample

A total of 21 banks were identified as the target audience. The data pertaining to seven banks was not accessible throughout the whole duration of the ten-year investigation. After undergoing a process of data screening and transformation, a total of 14 banks that are listed at the Karachi Stock Exchange were deemed suitable and so included in the final sample.

The approach used in this study is known as purposive sampling, which was previously utilized by Javid and Iqbal (2010).

12.1. Data collection

The research conducted in this study used panel data as its primary source of information. The collection of data for this study was derived from the audited annual reports of the individual banks, with the nature of the data being of secondary importance. The designated time frame for analysis was the fiscal year spanning from 2010 to 2020. All of the data was gathered from the official websites of the aforementioned institutions. The data was analyzed using the Pooled Regression Model, Fixed Effect Regression Model, Random Effect Regression Model, and Hausman Test.

12.2. Data Analysis

Quantitative data analysis approaches have been used to examine the correlation between intellectual capital and corporate success. The independent variable, namely intellectual capital, is determined by the calculation of VAIC (HEC + SCE + CEE). On the other hand, the dependent variable is assessed by many metrics including ROE, ROA, EPS, and M/B. The present study model incorporates the use of control variables, namely size, physical capacity, and leverage, to examine the impact of these variables on changes in income. The analysis methodologies used in this study were primarily rooted in descriptive statistics and the estimate of models using regression analysis. The association between variables was examined using correlation analysis.

12.3. Descriptive Statistics

Table 1 presents a comprehensive study of the dependent variables, namely Return on Equity (ROE), Return on Assets (ROA), Earnings per Share (EPS), Market-to-Book Ratio (MB), and Percentage Change in Revenue (% Δ R). Additionally, the independent factors, including Human Capital Efficiency (HCE), Structural Capital Efficiency (SCE), Customer Capital Efficiency (CEE), and Value-Added Intellectual Coefficient (VAIC), are examined. Furthermore, the analysis incorporates control variables such as firm size, leverage, and physical capacity. The descriptive statistics included measures such as the mean, standard deviation, lowest value, and maximum value. The results shown in the table indicate that there was a total of 140 observations.

The mean values for HEC and VAIC were found to be the highest, with values of 8.19 and 9.13, respectively. Additionally, these variables exhibited the largest standard deviations, with values of 1.00 and 1.2, respectively. The findings of this study indicate that the variables HEC and VAIC were identified as independent factors that accounted for a significant portion of the variation seen in the dependent variables.

Table 1. Descriptive Analysis

Variable	Obs.	Mean	Std. Dev.	Min	Max
ROE	140	.141401	.2978504	-1.989413	.4989051
ROA	140	.0122359	.0114449	-.05411	.037189
EPS	140	7.211071	7.793496	-19.04	24.47
M/B	140	1.703404	1.1517	.2823591	6.329687
%Δ R	140	7.346856	7.270791	.7541938	53.89794
HCE	140	8.199491	3.030441	1.006249	19.58107
SCE	140	.8587165	.0842842	.0062102	.9489303
CEE	140	.0798209	.0149422	.0082704	.1172332
VAIC	140	9.138029	3.088229	1.02073	20.61283
SIZE	140	19.47942	.9363442	17.03734	21.29379
DER	140	14.73844	8.095973	1.257592	76.5135
PC	140	.0324471	.0817958	.0043662	.9410532

12.4. Correlation Analysis

The correlation coefficient was used in E-Views to assess the association between the dependent and independent variables. The correlation matrix is shown in Table 5.2. The statistical significance of the correlations between variables is indicated by the p -value. A p -value that is less than 0.05 indicates a statistically significant correlation between variables at a 95% confidence range.

Table 2. Correlation Matrix

	ROE	ROA	EPS	MB	R	HCE	SCE	CEE	VAIC	SIZE	DER	PC
ROE	1											
ROA	0.8528*	1										
EPS	0.6174*	0.8512*	1									
MB	0.2424*	0.4626*	0.4873*	1								
R	0.0094	-0.0703	-0.1555	-0.1566	1							
HCE	0.1114	0.1521	-0.0359	0.0650	-0.0792	1						
SCE	0.5147*	0.4581*	0.2144*	-0.0036	-0.0043	0.6248*	1					
CEE	0.3385*	0.5152*	0.4384*	-0.0797	0.0713	0.2843*	0.5255*	1				
VAIC	0.1250	0.1643	-0.0273	0.0633	-0.0775	0.9997*	0.6430*	0.2982*	1			
SIZE	0.1312	0.2393*	0.5292*	0.0462	0.1410	-0.2737*	-0.0885	0.3608*	-0.2692*	1		
DER	-0.5475*	-0.5430*	-0.4230*	0.0217	0.1148	-0.0288	-0.1822*	-0.3059*	-0.0348*	0.0491	1	
PC	0.0459	0.0335	-0.0118	0.1106	-0.0450	-0.0303	0.0169	0.0083	-0.0292*	-0.0570	-0.0027	1

Significant at $p < 0.05$ *

There exists a positive correlation between human capital efficiency and financial performance indicators such as return on equity (ROE), return on assets (ROA), sales and customer equity (SCE), customer experience excellence (CEE), and changes in revenue. Conversely, there is a negative correlation between human capital efficiency and market value (MB) and earnings per share (EPS). The variables SCE and CEE have a positive correlation with the financial performance indicators of Return on Equity (ROE), Return on Assets (ROA), Earnings per Share (EPS), and Human Capital Efficiency (HCE). Conversely, they show a negative correlation with Market-to-Book ratio (MB) and Risk (R). In terms of percentage of sales, ROA, EPS, and MB are all negatively connected.

12.5. Regression Analysis

In order to examine the impact of information and communication technology (ICT) on several business performance indicators such as return on equity (ROE), return on assets (ROA), earnings per share (EPS), market value to book value ratio (MB), and percentage change in revenue (% Δ Revenue), a total of 10 regression models have been developed. These models also include control variables such firm size, leverage, and physical capacity.

Table 3. Regression Analysis for Model 1

Dependent Variable ROE	Pooled Regression (OLS)	Fixed Effect Regression Model (FE)	Random Effect Regression Model (RE)
β_0	-2.5985	-1.2204	-2.5985
	0.000	0.107	0.000
HCE	-0.0199	-0.0077	-0.0199
	0.0101	0.4539	0.0057
SCE	2.3758	2.1942	2.375
	0.0000	0.000	0.000
CEE	-3.8821	-4.7663	-3.882
	0.0179	0.009	0.0109
SIZE	0.0739	0.0121	0.0739
	0.0012	0.7572	0.0005
DER	-0.0184	-0.0213	-0.0184
	0.0000	0.0000	0.000
PC	0.1525	-0.0176	0.1525
	0.4675	0.9317	0.434
R ²	0.5646	0.66	0.56
ADJ. R ²	0.5449	0.60	0.54
F- Statistics	28.74	12.33	28.74
	0.000	0.000	0.000
Hausman Test			
Chi 2	27.45		
Prob > chi 2	0.0001		

The results of the fixed effect regression analysis suggest that there is no statistically significant positive influence of human capital expenditure (HCE) on the return on equity. However, there is a positive and statistically significant association between structural capital expenditure (SCE) and the return on equity. The presence of CEE (Corporate Environmental Expenditure) has been shown to have a substantial and adverse effect on the return on equity. The calculated probability value for the relationship between HCE and return on equity is 0.4539, which exceeds the commonly accepted significance level of 0.05. Therefore, based on this analysis, it can be concluded that there is no statistically significant positive link between HCE and return on equity. The statistical analysis reveals that the p-value for SCE

is 0.000, which is below the significance level of 0.05. Therefore, we can accept the alternative hypothesis and conclude that SCE has a positive and significant impact on business performance. On the other hand, the p-value for CEE is 0.009, indicating a significant relationship. However, this relationship is negative. Consequently, we reject the null hypothesis and conclude that CEE has a significant but not positive association with return on equity. The coefficient of determination, R², has a value of 0.66, indicating that about 66% of the variation in return on equity (ROE) can be attributed to a 1% change in human capital expenditure (HCE), social capital expenditure (SCE), cultural expenditure (CEE), and other relevant factors. Additionally, the F-statistic suggests that the overall fitness of the statistical test is satisfactory.

Based on the above empirical evidence, a fixed effect regression model may be constructed using the following regression equation:

$$\text{ROE} = -1.113 - 0.123\text{HCE} + 2.261\text{SCE} - 4.225\text{CEE} + 0.0130\text{SIZE} - 0.0124\text{DER} - 0.0243\text{PC}$$

Table 4. Regression Analysis for Model 2

Dependent Variable ROA	Pooled Regression (OLS)	Fixed Effect Regression Model (FE)	Random Effect Regression Model (RE)
β_0	-0.08473	0.0280	-0.05414
	0.000	0.278	0.0049
HCE	-0.00023	0.0003	1.66E-06
	0.4645	0.2896	0.99
SCE	0.0511	0.0535	0.0543
	0.0000	0.000	0.000
CEE	0.0821	0.0061	0.0168
	0.2083	0.919	0.7673
SIZE	0.0029	-0.0029	0.0013
	0.0013	0.028	0.1477
DER	-0.00064	-0.0005	-0.00061
	0.0000	0.000	0.000
PC	0.0051	0.0022	0.0033
	0.539	0.744	0.6255
R ²	0.520	0.73	0.46
ADJ. R ²	0.503	0.69	0.43
F- Statistics	24.50	17.23	19.03
	0.000	0.000	0.000
Hausman Test			
Chi 2	43.63		
Prob > chi 2	0.000		

The coefficient of determination, denoted as R², is seen to be 0.73. This value signifies that about 73% of the variation in the return on assets (ROA) can be attributed to a 1% change in the variables of human capital expenditure (HCE), social capital expenditure (SCE), and cultural capital expenditure (CEE). The F-statistic indicates that the test's fitness is satisfactory. The ROA will experience a shift of 0.0003 in response to a one rupee change in HCE. However, the ρ -value of HCE is 0.289, beyond the threshold of 0.05. Consequently, it can be inferred that HCE exhibits a positive but statistically insignificant relationship with the business success, as shown by the ROA of firms.

The Return on Assets (ROA) may be calculated using the following equation:

$$ROA = 0.0176 + 0.0243HCE + 0.0123 SCE + 0.0675CEE - 0.0431SIZE - 0.0152DER - 0.00229PC$$

Table 5. Regression Analysis for Model 3

Dependent Variable EPS	Pooled Regression (OLS)	Fixed Effect Regression Model (FE)	Random Effect Regression Model (RE)
β_0	-92.5974	-1.4516	-44.611
	0.000	0.9157	0.0002
HCE	-0.0518	0.3976	0.223
	0.8063	0.0355	0.1967
SCE	17.752	23.150	23.489
	0.0313	0.000	0.000
CEE	8.9566	-57.73	-60.16
	0.841	0.08	0.0585
SIZE	4.6229	-0.3175	2.0126
	0.0000	0.6571	0.001
DER	-0.3951	-0.250	-0.3119
	0.0000	0.000	0.000
PC	1.4069	0.3614	0.5112
	0.8078	0.9321	0.8905
R ²	0.516	0.83	0.33
ADJ. R ²	0.4949	0.81	0.30
F- Statistics	23.706	32.19	11.25
	0.0000	0.000	0.000
Hausman Test			
Chi 2	63.68		
Prob. > chi 2	0.000		

Based on the available empirical evidence, a fixed effect regression model may be constructed using the following regression equation.

The equation for earnings per share (EPS) may be expressed as follows: Based on the current findings of fixed effect regression model following regression equation can be formed:

$$\text{EPS} = -1.231 + 0.752\text{HCE} + 23.241\text{SCE} - 57.64\text{CEE} - 0.213\text{SIZE} - 0.314\text{DER} + 0.231\text{PC}$$

Table 6. Regression Analysis for Model 4

Dependent Variable MB	Pooled Regression (OLS)	Fixed Effect Regression Model (FE)	Random Effect Regression Model (RE)
β_0	-1.8615	14.939	5.0533
	0.4815	0.000	0.0514
HCE	0.0662	0.1090	0.083
	0.1316	0.0144	0.0335
SCE	0.0531	1.5787	1.370
	0.975	0.2208	0.274
CEE	-16.285	-33.145	-31.58
	0.0807	0.000	0.000
SIZE	0.2214	-0.6735	-0.143
	0.0853	0.0001	0.2775
DER	-0.0065	0.01593	0.0032
	0.6182	0.2156	0.779
PC	1.7978	1.3931	1.494
	0.1353	0.1153	0.087
R ²	0.049	0.58	0.19
ADJ. R ²	0.006	0.51	0.15
F- Statistics	1.15	8.92	5.21
	0.333	0.000	0.00007
Hausman Specification Test			
Chi 2	52.59		
Prob > chi 2	0.000		

The p-value for the variable HCE is 0.014, which is below the significance level of 0.05. Therefore, we may reject the null hypothesis and infer that there is a positive influence of HCE on MB. The chance of seeing a significant link between SCE and MB is 0.2208, which above the threshold of 0.05. This

suggests that there is no statistically significant relationship between SCE and MB. Therefore, we accept the null hypothesis. On the other hand, the p-value for CEE is 0.000, which is lower than 0.05. This implies a statistically significant negative association between CEE and MB. Based on the present empirical evidence, it is possible to formulate the following regression equation.

The mathematical equation for MB is represented as follows:

$$MB = 14.825 + 0.012HCE + 1.342SCE - 33.024CEE - 0.574SIZE + 0.124DER + 1.890PC$$

Table 7. Regression Analysis for Model 5

Dependent Variable %ΔR	Pooled Regression (OLS)	Fixed Effect Regression Model (FE)	Random Effect Regression Model (RE)
β ₀	-10.01	-171.72	-156.08
	0.5495	0.000	0.000
HCE	-0.2827	0.238	0.22
	0.308	0.178	0.200
SCE	4.3974	-4.572	-4.438
	0.6818	0.376	0.3884
CEE	48.191	1.13	9.518
	0.412	0.970	0.7564
SIZE	0.5257	9.2448	8.402
	0.5166	0.000	0.000
DER	0.1325	0.064	0.0724
	0.1101	0.209	0.1551
PC	-4.084	-2.73	-2.815
	0.5905	0.439	0.4251
R ²	0.044	0.832	0.60
ADJ. R ²	0.0016	0.80	0.58
F- Statistics	1.038	31.39	34.01
	0.40	0.000	0.000
Hausman Specification Test			
Chi 2	24.78		
Prob > chi 2	0.0004		

Nexus between intellectual capital and performance of commercial banks

The results of the fixed effect regression analysis suggest that there is no statistically significant relationship between HCE, SCE, and CEE with the percentage change in R. However, it was observed that HCE and CEE have a positive influence on the percentage change in R, while SCE has a negative impact. The percentage change in R will vary by 0.2388, -4.5728, and 1.131 when there is a one unit change in HCE, SCE, and CEE, respectively. The obtained p-value of 0.178 for the variable HCE is greater than the significance level of 0.05. Therefore, we fail to reject the null hypothesis and conclude that HCE has a positive but not statistically significant influence on the percentage change in R. The calculated probability for the SCE variable is -0.376, which is above the threshold of 0.05. This suggests that there is no statistically significant positive association present. The regression equation that may be formulated is as follows:

$$\% \Delta R = -169.81 + 0.1477HCE - 4.463SCE + 1.210CEE + 9.326SIZE + 0.0574DER - 2.642PC$$

Table 8. Regression Analysis for Model 6

Dependent Variable ROE	Pooled Regression (OLS)	Fixed Effect Regression Model (FE)	Random Effect Regression Model (RE)
β_0	-0.9843	-0.830	0.1558
	0.0379	0.117	0.8447
VAIC	0.0157	0.0347	0.021
	0.0253	0.0002	0.0034
SIZE	0.0040	-0.0013	0.055
	0.0051	0.973	0.035
DER	-0.0203	-0.020	-0.0207
	0.0000	0.000	0.000
PC	0.2216	-0.00262	0.113
	0.3824	0.9914	0.630
R ²	0.352	0.51	0.32
ADJ. R ²	0.333	0.44	0.31
F- Statistics	18.351	7.59	16.60
	0.000	0.000	0.000
Hausman Test			
Chi 2	14.55		
Prob. > chi 2	0.0057		

The results obtained from the pooled regression analysis indicate a statistically significant positive relationship between VAIC and ROE. The Hausman test indicates a p-value of 0.0057, which is below the conventional significance level of 0.05. Therefore, we may infer that the Fixed Effect regression model is superior than the Random Effect regression model. The F-statistic indicates that the model is a good match.

The return on equity (ROE) may be determined using the following equation:

$$ROE = 0.210 + 0.0421VAIC - 0.0190SIZE - 0.0198DER - 0.0129PC$$

Table 9. Regression Analysis for Model 7

Dependent Variable ROA	Pooled Regression (OLS)	Fixed Effect Regression Model (FE)	Random Effect Regression Model (RE)
β_0	-0.0636	0.0408	-0.2324
	0.0003	0.1114	0.2427
VAIC	0.00087	0.00170	0.0012
	0.0007	0.000	0.000
SIZE	0.0040	-0.00187	0.0017
	0.0000	0.1503	0.0861
DER	-0.00078	-0.00053	-0.00066
	0.000	0.1503	0.000
PC	0.0081	0.00328	0.00438
	0.38	0.6757	0.5704
R ²	0.419	0.66	0.33
ADJ. R ²	0.4022	0.61	0.31
F- Statistics	24.41	13.97	17.15
	0.0000	0.000	0.000
Hausman Test			
Chi 2	27.06		
Prob. > chi 2	0.000		

The findings obtained from the fixed effect regression analysis indicate a favorable and statistically significant relationship between VAIC and ROA. The coefficient of determination, R², is calculated to be 0.66, indicating a strong level of explanatory power for the model. The F-statistic indicates that the model is a suitable match.

The return on assets (ROA) may be calculated using the following equation:

$$ROA = 0.0381 + 0.0238VAIC - 0.0123SIZE - 0.0314DER - 0.0341PC$$

Table 10. Regression Analysis for Model 8

Dependent Variable EPS	Pooled Regression (OLS)	Fixed Effect Regression Model (FE)	Random Effect Regression Model (RE)
β_0	-83.752	14.279	-19.655
	0.000	0.27	0.0862
VAIC	0.2900	0.813	0.655
	0.073	0.000	0.000
SIZE	4.8558	-0.563	1.291
	0.000	0.390	0.025
DER	-0.430	-0.240	-0.291
	0.000	0.000	0.000
PC	2.249	0.470	0.5952
	0.701	0.905	0.8798
R ²	0.494	0.81	0.27
ADJ. R ²	0.479	0.78	0.25
F- Statistics	33.029	31.22	12.631
	0.000	0.000	0.000
Hausman Specification Test			
Chi 2	40.19		
Prob > chi 2	0.000		

Based on the above empirical evidence, a fixed effect regression model may be constructed using the following regression equation.

The equation for earnings per share (EPS) may be expressed as follows:

$$\text{EPS} = 14.360 + 0.794\text{VAIC} - 0.427\text{SIZE} - 0.153\text{DER} + 0.397\text{PC}$$

Table 11. Regression Analysis for Model 9

Dependent Variable MB	Pooled Regression (OLS)	Fixed Effect Regression Model (FE)	Random Effect Regression Model (RE)
β_0	-0.5023	20.926	10.561
	0.8221	0.000	0.000
VAIC	0.0327	0.060	0.038
	0.3231	0.0775	0.216
SIZE	0.0928	-1.039	-0.488
	0.396	0.000	0.0001
DER	0.0030	0.028	0.0182
	0.8026	0.031	0.1291
PC	1.6545	1.247	1.326
	0.1707	0.185	0.154
R ²	0.022	0.51	0.11
ADJ. R ²	-0.00647	0.45	0.09
F- Statistics	0.776	7.74	4.47
	0.5422	0.000	0.001
Hausman Test			
Chi 2	37.50		
Prob. > chi 2	0.000		

Based on the available empirical evidence, a fixed effect regression model may be constructed using the following regression equation. The equation for MB may be expressed as follows:

$$MB = 20.84 + 0.058VAIC - 1.041SIZE + 0.037DER + 1.14PC$$

The correlation between MB and intellectual capital is congruent with the results reported by Fourati and Affes (2013) as well as Zehri, Abdelbaki, and Bouabddellah (2012).

Table 12. Regression Analysis for Model 10

Dependent Variable %ΔR	Pooled Regression (OLS)	Fixed Effect Regression Model (FE)	Random Effect Regression Model (RE)
β ₀	-11.547	-173.132	-155.526
	0.4106	0.000	0.000
VAIC	-0.098	0.121	0.134
	0.633	0.342	0.286
SIZE	0.949	9.161	8.247
	0.1675	0.000	0.000
DER	0.096	0.067	0.072
	0.207	0.178	0.139
PC	-3.4608	-2.813	-2.862
	0.6469	0.4239	0.414
R ²	0.034	0.83	0.58
ADJ. R ²	0.0059	0.80	0.57
F- Statistics	1.208	35.32	47.77
	0.3101	0.000	0.000
Hausman Specification Test			
Chi 2	30.49		
Prob > chi 2	0.000		

According to the present results of the fixed effect regression model, the following regression equation may be derived: The equation for the change in the dependent variable, denoted as %ΔR, may be expressed as a linear combination of many independent variables. Specifically, it is given by the equation:

$$\% \Delta R = -173.456 + 0.264VAIC + 9.312SIZE + 0.421DER - 2.763PC$$

13. Conclusion, Recommendations & Limitations

Based on the aforementioned study, it was determined that there is no statistically significant correlation between HEC and the financial performance indicators of Return on Equity (ROE), Return on Assets (ROA), Earnings per Share (EPS), Market-to-Book ratio (MB), and Risk (R). However, a positive link was seen between HEC and ROE, MB, and ROA. The Variable Added Intellectual Coefficient (VAIC) has a positive correlation with all dependent variables, with the exception of customer pleasure. The explanatory power of all models demonstrates a strong level of fit. In conclusion, it can be said that the examination of intellectual capital in the present research reveals a noteworthy and favorable influence on corporate success.

14. Practical implication

This research provides useful insights for managers in the commercial banking sector, as it enhances their understanding of the significance of intellectual capital (IC) in creating value. Consequently, managers may effectively utilize this knowledge to optimize the organization's wealth. The use of this approach for measuring and assessing the performance of the organization will enhance the level of transparency in the review process. The provision of vital information on the performance of a company of importance to stakeholders would be facilitated.

Commercial banks may serve as a standard for other sectors in terms of efficiency by implementing tactics that aim to boost and improve company productivity. This approach would be beneficial for commercial banks. The allocation of scarce resources for intellectual and physical capital will be beneficial for the developing nation, namely Pakistan, in achieving a balance.

15. Limitation of Research

The present research exhibits several limitations in terms of its research components and the interpretation of its findings, which may impact its generalizability. It is important to acknowledge that due to the presence of distinct cultures and environments in different countries, this study may not be applicable universally to all countries and economies. This study only focuses on banking organizations listed on the Karachi Stock Exchange (KSE), and so may not accurately represent the performance of other corporations listed on other stock exchanges in Pakistan. This study used a singular, particular model for measuring intellectual capital, rather than doing a comparative analysis of several methodologies. The data obtained from financial statements generated using historical cost may vary from the results of current study due to adjustments and modifications made to financial statements based on current value.

16. Future Research Direction

Future study in the field of performance evaluation should focus on particular factors, such as human capital, in order to improve awareness of the significance of human capital as a crucial factor in assessing organizational performance. In order to acquire a more precise assessment of the intellectual capital of commercial banks, it is suggested that the competence of Pakistani commercial banks be evaluated in comparison to international banks. This comparative study would provide insights into areas where improvements may be made. In order to further investigate the relationship between intellectual capital (IC) and company performance, it is recommended that future research endeavors use a combination of qualitative and quantitative research approaches. Future study may be conducted by using several methodologies to assess the intellectual capital (IC) and explore the correlation between IC and organizational performance.

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INTEGRATING ARTIFICIAL INTELLIGENCE WITH GAME
THEORY: A STUDY ON REINFORCEMENT LEARNING IN
COOPERATIVE SETTINGS

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Abstract

Over the past two decades, the application of Artificial Intelligence—particularly Reinforcement Learning—to studying cooperative behaviour in the Public Goods Game has become increasingly widespread. We present a systematic review of this literature, highlighting factors that shape learning dynamics, such as agents' strategy adjustments over time and the role of social norms in cooperative behaviour. A pre-analytical clustering of 70 studies since 2002 identifies key research topics, including learning and conditional cooperation, punishment mechanisms, agent-based networks, moral learning, cooperation under uncertainty, and dynamic multi-objective learning in multiplayer settings. Trends show a growing interest in topics such as moral learning, cognitive aspects, cooperative artificial intelligence, cooperation under uncertainty, and collective risk, which have become increasingly relevant, especially after 2015.

JEL CLASSIFICATION: C63; C71; C73; C92; D90.

KEYWORDS: ARTIFICIAL AGENTS; GAME THEORY; LEARNING MODELS; EXPERIMENTAL DATA; COMPUTATIONAL MODELLING.

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1. Introduction and motivation

The study of cooperation, understood as an essential component of human and social behaviour, as well as a “*social-cognitive skill*” (Hermes et al., 2016, p. 1), constitutes a crucial element in the comprehension of the functioning of collective actions and cooperative decision-making (among others, see Olson, 1965). In recent decades, the study of the factors that influence individuals’ cooperative behaviour, even when it is costly, has become a central theme in the Social Sciences, including Economics, as well as in methodological approaches related to Artificial Intelligence and Computational Sciences (e.g., Boza & Számadó, 2010; Sasaki et al., 2015; Zhang & Chen, 2016). From a broad perspective, the study of cooperation is critically essential for resolving significant local and global issues. Such issues include, but are not limited to, climate change, governance of public goods and common resources, and health crisis management. These issues require a collective and coordinated response from decision-makers with often divergent interests. This is particularly evident in social dilemmas, where the pursuit of individual self-interest can result in detrimental outcomes to the collective good (e.g., Dawes, 1980).

Within cooperative settings, the Public Goods Game can be considered one of the most widely used models for studying cooperative dynamics in contexts of interaction between human and non-human economic agents (Wu et al., 2014). Simply put, some assets are invested to create, produce, or maintain a public good in this model of society, and a return (payoff) is regained. Therefore, this model can illustrate a contributory scenario, thereby facilitating the emergence of an underlying social dilemma. In the Public Goods Game, there are typically more than two players, each with an initial allocation of resources to contribute to the common fund (i.e., the public good or as a function of the public good). Thus, each player is presented with the decision of whether or not to contribute to the public good with their resources and, if so, to what extent. Alternatively, they may choose to pursue self-interest, benefiting from the public good without contributing to its creation, which is called free-riding behaviour in advanced microeconomics. The total resources collected in the common fund are multiplied by a factor, the marginal per capita return (MPCR), and then

redistributed equally among all players, regardless of whether they contributed—or not (see Wang et al., 2024). It is worthwhile to consider that in the standard and linear version of the Public Goods Game, the Nash Equilibrium of the game suggests that each player maximises their utility by acting as a free-rider, that is to say, by not contributing to the common fund (Casady & Maynes, 1998). Nevertheless, the optimal collective welfare outcome would be achieved if all players were to contribute the maximum amount of available resources to the common fund. This contrast between individual interest and collective welfare represents a fundamental aspect of the Public Goods Game dilemma (Van Dijk et al., 2003). Such a dilemma makes the Public Goods Game an appropriate investigative framework for elucidating the mechanisms underlying cooperation and the factors that influence it, including reciprocity, resource inequality, and punishment and reward mechanisms (e.g., Fehr & Gächter, 2000). The Public Goods Game represents a valuable framework for investigating cooperative behaviour in human economic agents through experimental economics (e.g., Fehr & Gächter, 2002) and in artificial agents through simulations (e.g., Szolnoki & Perc, 2010). It is also noteworthy that the Public Goods Game model can be used to design both non-cooperative Game Theory (von Neumann & Morgenstern, 1944) and Evolutionary Game Theory (Maynard Smith, 1982; Weibull, 1997) studies. Prior research, both experimental and computational, has demonstrated that reciprocity mechanisms, including direct reciprocity, indirect reciprocity, and network reciprocity (Croson, 2007), can sustain cooperation in the Public Goods Game. These mechanisms provide incentives for economic agents to engage in cooperative behaviour through the dynamics of exchange and social interaction, whereby cooperation is directly or indirectly rewarded with group benefits.

Despite its apparent simplicity, the Public Goods Game model has been expanded in numerous ways to more accurately reflect real-world scenarios, typically economic and non-economic. Furthermore, the model can be employed to investigate the influence of environmental and social variables on the promotion or inhibition of cooperation. It will be observed that these variables are of particular relevance to the design of artificial agents that reflect human behaviour in scenarios that replicate real-world problems. In this context, an examination of the literature reveals that the application of Reinforcement Learning (Bush & Mosteller, 1951; Suppes & Atkinson,

1960; Cross, 1983; Roth & Erev, 1995; Erev & Roth, 1998) in the context of the Public Goods Game provides insightful perspectives for understanding cooperative interactions. In addition, the application of Reinforcement Learning enables the simulation of realistic scenarios and the investigation of evolutionary strategies in multiplayer environments.

It is becoming increasingly evident that Reinforcement Learning represents a valuable approach for studying cooperative dynamics in the context of the Public Goods Game. As will be discussed in detail in the dedicated section, Reinforcement Learning represents a promising approach for modelling decision-making and strategic learning processes among artificial agents, particularly in complex scenarios where individuals seek to balance their own interests with the collective well-being. However, the existing literature on the application of Reinforcement Learning algorithms in the context of the Public Goods Game is fragmented. To the best of our knowledge, no study has yet provided a systematic review of the literature in this area, including an examination of the principal research topics and findings that have emerged.

In light of the considerations above and emerging motivations, we ask ourselves the following question: Which Reinforcement Learning algorithms are most commonly used to examine cooperative behaviour and strategic learning in the context of the Public Goods Game? What are the core topics and how might they be structured to facilitate a comprehensive overview of the literature? What has been the trajectory of scholarly interest in cooperation and strategic learning over time, and which topics have emerged as the most relevant?

To address these questions, this work provides a systematic review of the literature on Reinforcement Learning applied in the context of the Public Goods Game. The aim is to systematically review the literature, identify the principal topics, and delineate research trends. This objective is achieved through pre-analytical clustering, which organises the existing literature into logically defined and thematically based clusters. In order to gain insight into the evolution of scientific interest over time and identify the most pertinent topics, an examination of the temporal evolution of these research topics is undertaken.

The work makes a twofold contribution: First, it provides an overview of the academic literature that has employed Reinforcement Learning as a modelling approach to study cooperation and strategic learning in the Public Goods Game. Second, it identifies potential avenues for further research and

suggests areas for high-impact future investigation. Specific attention is paid to emerging topics, including moral learning and cooperation under uncertainty and collective risk.

The remainder of this work is structured as follows: Section 2 provides a review of the theoretical framework of reinforcement learning, with particular attention paid to the Q-learning algorithm in the context of the Public Goods Game. In doing so, it also provides an algorithmic representation of the Q-learning. Section 3 presents a systematic literature review, with a particular focus on the key findings of the existing work. Section 4 analyses the central topics addressed in the selected works and examines their evolution over time. Section 5 discusses the main findings, provides insights for future research and concludes the work.

2. Understanding the fundamentals of the reinforcement learning model

The Reinforcement Learning model constitutes a class of adaptive behaviour models in which agents adjust the probability of selecting specific strategies based on past outcomes (e.g., Bicchieri et al., 2018). It is a subfield of Machine Learning that is concerned with the training of agents in order to enable them to learn from interactions within an environment, with the objective of maximising cumulative long-term rewards. The utilisation of Reinforcement Learning enables artificial agents to autonomously determine their subsequent action based on the feedback received, utilising a reinforcement signal or reward to optimise their future behaviour without the necessity for supervision (Manchon & Zhen, 2010).

Computational models, such as those based on Reinforcement Learning, are employed to map decision-making processes and to investigate optimal responses (Sutton & Barto, 1998). Reinforcement Learning models are particularly well-suited to the study of human decision-making in uncertain or evolving situations, as they are capable of capturing adaptive behaviours.

Furthermore, Reinforcement Learning incorporates the concept of policies, which direct agents to link states to actions that optimise overall value. This offers a quantitative insight into human decision-making styles and cognitive processes (Kishida & Montague, 2013). The principles of Reinforcement Learning, which have their roots in psychological research, have been applied to economic games such as bargaining and auctions. In such games, agents learn optimal strategies with limited rationality, based

solely on feedback regarding the resulting payoffs (Roth & Erev, 1995). The advent of advanced Artificial Intelligence techniques has enabled the deployment of Reinforcement Learning to train agents capable of strategic gameplay, exhibiting effective resource management and resilience within groups (Melendez et al., 2022).

A review of the literature on computational game theory, with a particular focus on the use of Reinforcement Learning in the context of the Public Goods Game, reveals that the version of the Reinforcement Learning model that is most frequently employed in this context is that proposed by Roth & Erev (1995) and Erev & Roth (1998). In formal terms, as set forth by Erev & Roth (1998), the model can be represented as follows: At time $t=1$, before the agent (player) n has gained any experience, it is assumed that the agent has an initial propensity to adopt its k th pure strategy (e.g., cooperate or defect), represented by non-negative values defined by $q_{nk}(1)$. Erev & Roth (1998), in the basic version of their model, assume that each player has the same initial propensity for each pure strategy available. Specifically, for each agent n ,

$$q_{nk}(1) = q_{nj}(1) \quad \text{for all pure strategies } k, j. \quad (1)$$

Subsequently, the authors introduced the reinforcement function as follows: The reinforcement, for each agent, of receiving a payoff x is given by a specific increasing function, denoted by $R(x)$. Based on this, and including the smallest achievable payoff, x_{min} , the reinforcement function can be written as:

$$R(x) = x - x_{min} \quad (2)$$

At this point, the authors present the updating propensities phase, which can be described as follows: If agent n plays its k th pure strategy at time t and receives a reinforcement $R(x)$, the propensity to adopt strategy j can be updated in this way:

$$q_{nj}(t+1) = \begin{cases} q_{nj}(t) + R(x) & \text{if } j = k \\ q_{nj}(t) & \text{otherwise} \end{cases} \quad (3)$$

Additionally, Erev & Roth (1998) defined the probabilistic choice rule. This rule implies that the probability that agent n adopts the k th pure strategy at time t , $p_{nk}(t)$, is given by:

$$p_{nk}(t) = q_{nk}(t) / \sum q_{nj}(t) \tag{4}$$

In Eq. (4), it is necessary to consider that the summation refers to all pure strategies, j , of agent n .

The model demonstrates that, in general, successful pure strategies are played more frequently over time than less successful ones. In the initial stages, the learning curve is relatively steep, but gradually flattens as positive reinforcement increases the probability of selecting a successful strategy over time. Consequently, the reinforcement $R(x)$ from playing a pure strategy k at time t has a stronger effect on $p_{nk}(t)$ when t is small, with this impact diminishing as t increases (Erev & Roth, 1998).

This model has been employed extensively in a multitude of studies investigating the evolution of agent behaviour over time, particularly within the context of computational game theory.

In light of the above, it is necessary to consider that within the existing literature on Reinforcement Learning applied to the Public Goods Game, one of the most frequently utilised algorithms in this field is Q-learning (see, for example, Allen et al., 2018; Zhang et al., 2024). In this context, Q-learning has been employed as a model for analysing the evolution of individual decision-making in repeated interactions. This algorithm has frequently demonstrated superior performance in comparison to traditional models (Rosenfeld & Kraus, 2018).

Formally, in the arena of Public Goods Game, the value of choosing a contribution a in state s is represented by a table (Q-table). The Q-table is a data structure in which each agent stores $Q(s,a)$ values, representing the estimated value of each state-action pair. In essence, the Q-table contains a mapping indicating the advantage of choosing an action a in a specific state s . These values are updated each round and serve as a reference for deciding the best action to take, thus enabling the agent to improve its choices over time. The updating of the Q-table is defined by the following equation:

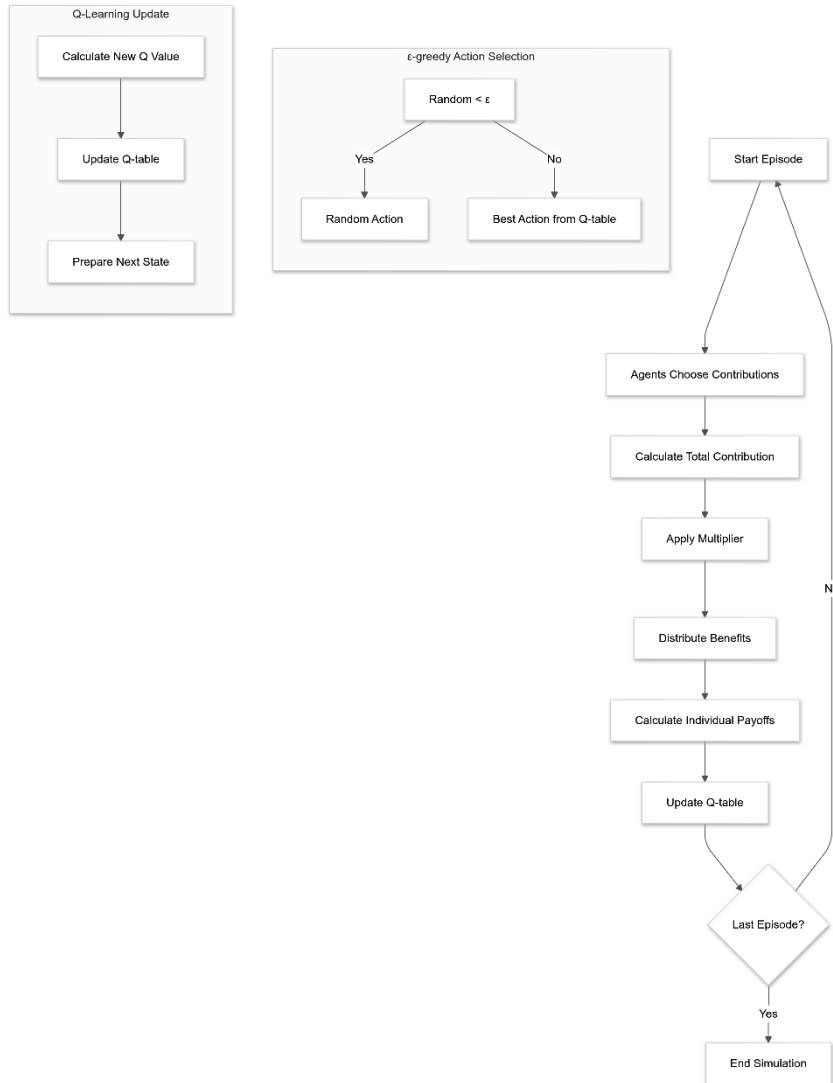
$$Q(s_t, a_t) \leftarrow Q(s_t, a_t) + \alpha \left[r_t + \gamma \max_{a'} Q(s_{t+1}, a') - Q(s_t, a_t) \right] \quad (5)$$

where α is the learning rate, which controls the speed at which the agent updates the values in the Q-table. A value of α close to 1 indicates that the agent assigns significant weight to the new results, whereas a low value suggests that the agent tends to maintain the existing estimate, modifying it only gradually. The term r_t represents the immediate reward obtained by the agent at time t . The parameter γ is referred to as the discount factor, which serves to regulate the relative importance of future gains in comparison to immediate ones. When γ is close to 1, the agent is inclined to prioritise long-term gains, whereas a γ close to 0 indicates a focus on immediate gains. The value of $\max_{a'} Q(s_{t+1}, a')$ represents the maximum expected value of possible actions in the subsequent state.

The agent employs an ϵ -Greedy algorithm to achieve an optimal balance between exploration and exploitation of strategies. The agent selects the “best action,” defined as the option with the highest value in the Q-table, with a probability of $1-\epsilon$. This decision demonstrates the agent’s inclination to capitalise on the information they have already acquired. Nonetheless, with probability ϵ , the agent selects a random action, thereby exploring novel possibilities.

Figure 1 provides an algorithmic representation of Q-learning employed in the context of the Public Goods Game. In particular, the flow chart is divided into three main sections: The updating of the Q-table, the selection of actions according to the ϵ -Greedy strategy, and the overall flow of an episode (round) of the game. This final section is of particular interest. Each episode commences with the selection of contributions by the agents, followed by the calculation of the total contribution, the application of the multiplier and the distribution of benefits. Subsequently, individual payoffs are calculated and the Q-table is updated. At the conclusion of each episode, the system verifies whether the final episode has been reached. If this is the case, the simulation terminates.

Figure 1. An algorithmic representation for Q-Learning application in the Public Goods Game.



Source: Authors' own elaboration.

3. Reinforcement Learning in the Public Goods Game: A systematic literature review

This section presents a systematic review of the literature that applies Reinforcement Learning within the context of the Public Goods Game, with the objective of examining the dynamics of cooperative behaviour and learning among interacting agents. In light of the above sections, it is worthwhile to consider the findings of numerous studies investigating the potential ability of artificial agents to learn cooperative behaviour through repeated and reciprocal interactions, utilising Reinforcement Learning algorithms. Among these, we may cite the study by Amado et al. (2015), in which the authors investigate the impact of memory and learning on the evolution of cooperation in agents. The authors perform a comparative analysis of two learning models: Dynamic and static learning. In dynamic learning, the agents, conceived as players, modify their strategy as the game progresses. In contrast, under static learning, the strategy is fixed at the outset of the game and remains unaltered. The findings of the simulation suggest that the level of cooperation is dependent on memory. In light of these findings, this study underscores the pivotal role of adaptive learning in promoting cooperation in the Public Goods Game through a strategic evolutionary lens. The studies by Ezaki et al. (2016) and Horita et al. (2017) concentrate on the phenomenon of conditional cooperation in contexts where multiple agents interact with each other in the Public Goods Game. The authors highlight the importance of Reinforcement Learning in the evolution of adaptive cooperative behaviour. Similarly, Allen et al. (2018) investigate the impact of Q-learning on the emergence of conditional cooperation. The results demonstrate that optimally calibrated learning parameters can enhance the level of cooperation among players, which in turn leads to augmented contributions to the public good. Khalvati et al. (2019) examine group decision-making through the lens of a Bayesian model that is grounded in the theoretical framework of partially observable Markov decision processes (POMDPs). In particular, the Bayesian model is compared with a Reinforcement Learning model, demonstrating that the Bayesian model is more effective at simulating human behaviour in group decision-making than traditional Reinforcement Learning models. Furthermore, Li & Hao (2019) and Leimar & McNamara (2019) investigate the circumstances under which cooperation can be more readily established when agents overestimate the costs associated with selfish behaviour,

thereby reducing the likelihood of defection. In particular, as demonstrated by Li & Hao (2019), in a repeated Public Goods Game, global cooperation can be conceptualised as the optimal strategy for individual players, resulting in sustained cooperation even when opponents are self-learning and colluding. In order to reproduce the experimental outcomes observed in Public Goods Games, Tomassini & Antonioni (2019) utilise computational behavioural models, thereby demonstrating that agent-based simulations can anticipate cooperative scenarios prior to experimentation with humans in the real world. Godara et al. (2022) present a model of agents with bounded rationality in the Public Goods Game, employing a conventional Markov chain formulation to optimise future rewards. In particular, artificial agents simulate human behaviour observed in experiments, adopting an alternative approach to evolutionary learning. The study by Godara et al. (2022) demonstrated that the discount factor, which determines the valuation of future gains relative to immediate rewards, is a key parameter influencing the behaviour of the agents. In a recent study, Bogdan et al. (2023) and Bühren et al. (2023) investigated the role of reciprocity and conditional cooperation in an agent-based scenario. The results indicate that external incentives, such as rewards or punishments, can reinforce cooperation regardless of the individual's earnings. To investigate the influence of dynamic rewards on agent behaviour in the Public Goods Game, Zhang et al. (2024) conduct an agent-based simulation utilising Reinforcement Learning. The findings indicate that variable rewards are more effective than fixed rewards in promoting long-term, sustainable cooperation.

The study conducted by Wang and colleagues (2024) examines the role of conformity, understood as the tendency of humans to align their behaviour with that of their peers, in promoting cooperation within heterogeneous populations. In essence, the authors demonstrate that conformity can either facilitate or impede cooperation, contingent on the distribution of resources among agents. Specifically, at high levels of synergy, conformists facilitate cooperation among individuals with different initial endowments. Nevertheless, at low levels of synergy, they may inhibit cooperation, particularly among those with higher initial endowments. The impact of conformists is contingent upon the clusters to which they belong. In contexts characterised by lower wealth inequality, conformist tendencies have been demonstrated to enhance cooperation. Conversely, even minimal conformist tendencies in contexts of inequality can have a profound impact on the

dynamics of cooperation. The study indicates that a reduction in inequality is conducive to the promotion of cooperation. Similarly, Czupryna et al. (2024) and Liu & Li (2025) present evidence that agents' perception of fairness, modelled through Reinforcement Learning, facilitates cooperation by reducing the impact of resource inequalities. In their study, Ferraro & Vossler (2006) examine the role of confusion in public goods games. The researchers conducted experiments with human participants and simulations with artificial agents to examine the influence of a misunderstanding of the game on participants' behaviour. The authors argue that it is possible to recalibrate the confusion of economic agents through a redesign of the game, thereby modifying the level of contribution to the public good. Hicri & Kirman (2007) examine the phenomenon of emergent coordination in the Public Goods Game, demonstrating that individual learning cannot fully account for aggregate behaviour, given the considerable variability introduced by the heterogeneity of participants. In particular, group dynamics and interactions appear to result in a range of contributions, with not all groups necessarily exhibiting the typical decline in cooperation observed at the aggregate level. The variation in individual behaviour may not be readily explained by straightforward factors such as altruism, as some individuals may signal through their contributions in an effort to influence others. Although the prevalence of free-riding is observed to increase on average, individual behaviours remain diverse. Furthermore, the complexity of these interactions may be overlooked in aggregate results, which could suggest that individuals may not learn in the same way as the group as a whole.

The emergence of the free-rider problem in the Public Goods Game has prompted scholars such as Bayer et al. (2009) and Castañón et al. (2023) to examine the role of altruistic punishments in these games. The implementation of punishments was found to result in an increase in long-term cooperation among agents. de Jong & Tuyls (2011) proposed a computational model of fairness inspired by human behaviour, with the aim of addressing social dilemmas in multi-agent systems. While not explicitly focused on Reinforcement Learning, the fairness model, which incorporates decentralised sanctions, is suitably adaptable to the cooperative scenarios of the Public Goods Game. Similarly, Villatoro et al. (2014) and Godara & Herminghaus (2023) illustrate that group punishment serves not only to penalise free-riders, but also functions as a normative signal that reinforces the norms of cooperation. In this regard, it is necessary to consider that cooperation rules, which can be studied through the lens of Game Theory,

may emerge in different contexts that stylise real-life problems. This is demonstrated by the work of Halty et al. (2020), in which the authors examine scheduling problems in Cloud Manufacturing systems through decentralised optimisation based on Game Theory. The findings of this study suggest that Reinforcement Learning may represent an effective approach to addressing resource allocation issues in manufacturing systems. Yaman et al. (2023) investigate the function of decentralised social sanctions in enabling a division of labour between self-taught individuals and maintaining a cooperative equilibrium within the group. The aforementioned evidence allows us to reasonably conclude that the maintenance of cooperative behaviour is a crucial factor in facilitating an increase in collective well-being. In this regard, Kol'vecková et al. (2021) present a model of endogenous shared punishment in Public Goods Games with a threshold. Their findings demonstrate that collective voting to decide on the punishment of free-riders would significantly increase efficiency in achieving the common goal. In a similar fashion, Zhang et al. (2024) adopt Q-learning in the context of the Public Goods Game with loners. Their findings demonstrate that integrating loner strategies with Reinforcement Learning algorithms can maintain a balance between cooperation and defection, thereby contributing to long-term population stability.

A review of the literature on the subject reveals that a significant number of scholars have concentrated their research on the role of social networks and complex interactive structures in facilitating cooperation between and within groups of agents. In addition, Grinberg & Todorov (2016) introduce a multi-agent simulation platform for the investigation of large-scale social interactions. They observe that cognitive and computational models can accurately replicate observed cooperative behaviour. Lugovskyy et al. (2017) examine the phenomenon of cooperation in repeated Public Goods Games with probabilistic or fixed endings. The results demonstrate that cooperation is significantly reduced in the final round of games with fixed endings in comparison to those with probabilistic ones. Similarly, Han et al. (2017) investigate the potential of default engagement and participation in Public Goods Games to drive the evolution of cooperation in social networks, through the processes of imitation and mutation of agents. In the context of agent-based social networks, Bennati et al. (2018) examine the strategies by which agents contribute to the provision of smart city services.

This is achieved by applying public goods theory and utilising simulations based on real data, with the objective of studying resource management in contexts of mobility and electric vehicle charging. In a similar manner, Klima et al. (2018) utilise the Public Goods Game as a framework to examine phenomena such as collective resource management, demonstrating how Reinforcement Learning agents can learn sustainability and cooperation strategies. Wu et al. (2018) apply coalitional game theory in conjunction with Reinforcement Learning to enhance communications in vehicular networks, thereby demonstrating how cooperative learning between agents can enhance efficiency in communications in complex environments. Lindström & Tobler (2018) investigate the emergence of ostracism as an incidental consequence of reinforcement learning processes in the context of repeated games. The study demonstrates that repeated learning based on rewards and punishments can result in ostracism, even in the absence of any punitive intent. This work presents a further application of Reinforcement Learning in agent-based social networks, illustrating how the selection of social partners is influenced by learning mechanisms. In a further development of this field, Barfuss et al. (2020) present an evolutionary model that combines Reinforcement Learning with Game Theory. This methodological approach demonstrates that cooperation can evolve in complex networks, thus facilitating the study of collective phenomena. The study focuses on the examination of the interplay between factors influencing cooperation in a Public Goods Game context related to climate change. It was demonstrated that, in scenarios of severe and distant collapse, concern for the future has the potential to transform the game from a "tragedy of the commons" to one of coordination or even cooperation dominance. In light of previous research, Santos et al. (2020) and Domingos et al. (2021) have investigated the potential of Reinforcement Learning as a means of modelling decisions within uncertain contexts. The findings have contributed to a growing body of evidence suggesting that Reinforcement Learning can inform decision-making in situations characterised by collective risk, such as climate action. Nevertheless, this approach has also given rise to a polarised discourse surrounding the use of reinforcement learning in such contexts. However, Jager & Reisinger (2022) examine the utilisation of artificial neural networks to simulate human behaviour in the Public Goods Game, demonstrating that these networks are capable of accurately replicating human experimental outcomes. Jia et al. (2022) examine the restructuring of social connections and demonstrate that even

minor structural alterations can have a considerable impact on cooperation in public goods contexts. Similarly, Bai et al. (2024) and Du et al. (2024) investigate the dynamics of social networks, demonstrating that the updating of social connections can positively impact levels of cooperation. In a strict sense, the term "social networks" encompasses not only those networks created by humans but also those created by artificial agents. This is exemplified by the work of Zou & Huang (2024), who integrated reputation into reinforcement learning models, demonstrating that a focus on social reputation fosters the evolution of cooperation in hypergraph contexts. Similarly, You et al. (2025) investigate reinforcement learning in a multi-layered context. The authors utilise a two-layer network model, whereby humans exert influence over agents through Bush-Mosteller Reinforcement Learning model (Bush & Mosteller, 1951). This illustrates how cooperation can emerge and be sustained through external influences. This study represents a further contribution to the use of Reinforcement Learning to simulate the evolution of cooperation in complex, dynamic environments, which are stylised through the Public Goods Game.

Furthermore, additional studies are investigating the potential of Reinforcement Learning to elucidate the concepts of moral learning, cognitive functioning and the development of cooperative artificial intelligence (AI) within the context of the Public Goods Game. Among the various studies, the work of Seymour et al. (2007) is worthy of particular mention, as it analysed the neurobiological mechanisms underlying altruistic punishment. The findings indicate that Reinforcement Learning can effectively serve as a modelling tool for punitive behaviour, thereby facilitating promotion of cooperation. Concurrently, Biele et al. (2008) and Cushman et al. (2017) investigate the processes through which individuals acquire moral values and social norms in the context of cooperative games. The results demonstrate that Reinforcement Learning is an effective method for modelling the acquisition of complex social norms. ManChon & Zhen (2010) examine the manner in which reinforcement learning agents learn and develop optimal profit strategies in the public goods game, accurately replicating human experimental behaviour. Similarly, Hughes et al. (2018) introduce the concept of inequity aversion into Markovian models, demonstrating that the presence of inequity aversion would result in an increase in cooperation over time in long-term Public Goods Games through

the allocation of time credit. This allows agents to achieve a balance between immediate and future benefits. Newton (2018) presents an analysis of the evolution of behavioural rules in the context of economics and social science. The author demonstrates how relatively straightforward decision-making rules, including those based on Reinforcement Learning, can give rise to multifaceted social outcomes. Rusch et al. (2020) present a framework for the classification of Theory of Mind (ToM) tasks in the context of social dilemmas. The results of the study indicate that Reinforcement Learning can be utilised to model the comprehension of others' mental states. The simulation illustrates the significance of integrating interactivity and uncertainty into investigations of ToM capacities in social decision-making. This emphasises that more complex and interactive tasks conducted in uncertain conditions are more effective in eliciting ToM processes. Furthermore, computational models that capture these dynamics can facilitate an understanding of the underlying cognitive and neural mechanisms involved. Among the numerous factors that can influence the decision-making processes of economic agents, communication constitutes a particularly salient element. In this regard, Orzan et al. (2023) explore the emergence of communication in Public Goods Games in contexts that combine cooperation and competition through the use of Reinforcement Learning agent simulation. The findings illustrate that communication can enhance cooperation, yet it can also be exploited as a means of deceiving other participants. López de Aberasturi Gómez et al. (2024) employ multi-agent models to investigate the potential of Reinforcement Learning agents to approximate Nash equilibria in cooperation scenarios pertaining to discretionary group tasks. The study illustrates the capacity of conventional Artificial Intelligence techniques, such as Reinforcement Learning, to replicate typical human behavioural characteristics. In this context, Koster et al. (2022) introduce the concept of Democratic AI, employing Deep Reinforcement Learning to develop economic mechanisms with the objective of replicating those that are preferred by humans in fund redistribution games. The results demonstrate that AI can be employed to develop policies that optimise cooperation and satisfaction of human preferences.

It is also worthy of note that other research in this field has investigated the impact of uncertainty and risk on cooperation in the Public Goods Game, employing models based on Reinforcement Learning. Such studies provide significant insights into the dynamics of collective risk. Among the existing

studies, we mention the work of Park et al. (2019), which examines the neurocomputational mechanisms underlying group strategic decision-making. The study employs functional magnetic resonance imaging (fMRI) models to identify the brain areas involved in balancing individual and collective benefits in the Public Goods Game. In particular, the study employs Reinforcement Learning to model the manner in which participants update their beliefs regarding the decisions of others in a Public Goods Game. To be more precise, a Reinforcement Learning algorithm is utilised to update participants' beliefs regarding the probability of others free-riding based on the social prediction error, which is adjusted by a learning rate. Similarly, Pereira and Santos (2019) examine the role of counterfactual thinking in the evolution of cooperation. The results demonstrate that even a relatively small proportion of individuals engaging in counterfactual reasoning can significantly influence the collective tendency towards increased cooperation. Kumar & Dutt (2020) employ an expectancy-valence-learning model to examine the complexities of climate change dilemmas. The research demonstrates that participants learn to invest in a public fund to mitigate the risk of climate change failure, thereby underscoring the collective nature of this threat. The studies by Merhej et al. (2021, 2022) examine the influence of wealth disparity on the propensity to collaborate in contexts where the viability of a public good hinges on collective endeavour. The results indicate that when there is a greater perception of diversified risks, wealthier players are less likely to contribute to the public good in comparison to their less affluent counterparts.

In considering the diverse applications of Reinforcement Learning algorithms within the context of the Public Goods Game, it is necessary to cite works that concentrate on dynamic multi-objective learning, cooperation, and imitation in multiplayer scenarios. Among the existing works, we cite Cooper & Stockman (2002), which examines the behaviour of both humans and artificial agents in step-level public games, thereby elucidating the manner in which fairness and learning influence decisions. The authors integrate two hypotheses, namely fairness and learning, into a Reinforcement Learning model that most accurately represents the experimental data. The model illustrates that players tend to deviate from dominant strategies due to considerations of fairness. Furthermore, Mak & Zwick (2010) investigate coordination challenges in markets with network

externalities, demonstrating how Reinforcement Learning can be employed to enhance investment decisions in infrastructure-related Public Goods Game scenarios with network effects. In a further contribution to this field, Christoforou et al. (2013) examine cooperation in crowd computing systems using an evolutionary Reinforcement Learning approach. Although the authors employ implicit Reinforcement Learning, their focus is on the spontaneous evolution of cooperative responses through numerical simulations, as opposed to the utilisation of formal Reinforcement Learning algorithms. Salazar et al. (2022) investigate the role of generalised reciprocity in group norms in greater detail when examining the phenomenon of cooperation in multiplayer scenarios. Their findings demonstrate that reciprocity mechanisms, even in the absence of direct monitoring of others' behaviour, can foster the emergence of cooperation. Pal & Sengupta (2022) investigate the potential of an aspirational-based learning model in Public Goods Games, concluding that a modest restructuring of social connections may facilitate the emergence of altruistic cooperative strategies. In a recent study, Odouard et al. (2023) investigated the impact of norm internalisation in Public Goods Games. The results indicate that small groups of norm internalisers can promote cooperation among other agents, even when they represent a minority. In a further contribution to this field, Couto & Pal (2023) apply introspection dynamics to asymmetric multiplayer games, exploring how players modify their strategies by comparing alternatives. In particular, the authors examine strategic learning in asymmetrical contexts, offering a valuable framework for Public Goods Games with multi-agent systems. Han et al. (2023) apply the Bush-Mosteller model (Bush & Mosteller, 1951) to demonstrate how expectations of gain positively influence cooperative behaviour in repeated games, such as the Public Goods Game. Similarly, Wang et al. (2023) examine the combined effects of adaptive reinforcement rules and rewards, demonstrating that self-referential Q-learning in conjunction with dynamic rewards is more effective than static learning systems in promoting cooperation. In a similar vein, Shen et al. (2024) employed a combination of Q-learning and the Fermi update rule to investigate the evolutionary dynamics of spatial public goods games. The findings indicate that the integration of learning and imitation is conducive to fostering cooperation within structured contexts. In the context of structured environments, Usvitskiy (2024) examines the influence of pioneer selection in the Public Goods Game on long-term cooperation. The findings suggest that high-

impact agents are inclined to invest in less developed locations, thereby creating incentives for other agents to follow their example. Orzan et al. (2024) introduce the concept of multi-objective learning in the Public Goods Game, demonstrating that risk preferences and environmental uncertainty exert a significant influence on both cooperative and competitive behaviour. In a related study, Wang and Yang (2024) explore the influence of conformity in social dilemma contexts. The results indicate that conformity may have a dualistic effect, potentially fostering cooperation in less severe scenarios but hindering it in more challenging dilemmas.

In conclusion, the application of Reinforcement Learning models in conjunction with multi-agent simulations provides insights of considerable value for the understanding of cooperation dynamics in the Public Goods Game. Nevertheless, further investigation through pre-analytic clustering is required to gain a more comprehensive and structured overview of the existing literature. This would entail organising the literature into clusters based on key topics to identify recurring patterns and emerging research areas.

4. Pre-analytical clustering

A clustering study was conducted to gain a more comprehensive understanding of the diverse range of topics addressed in the existing literature on the subject under investigation (in this regard, see Spitzreck & Hansen, 2010). This section presents the summary results of the study, which systematises the seventy papers in the review into six main topics. These topics were identified through a systematic process of exploratory analysis of textual data. This process organised the observed data into groups and categorised them, guided by a logical approach and conceptual categories emerging from the literature. Consequently, the six topics are hereafter regarded as clusters. As discussed in further detail below, the papers included in the review are grouped according to topic areas that address common research questions or key concepts. This approach facilitates a pre-analytical study of research trends and gaps. Subsequently, an investigation is conducted into the temporal distribution of the papers by cluster. This provides a relatively broader and more detailed view of the topics covered and their evolution over time. Based on the above, Table 1

presents the main topics identified during the review selection and inclusion of papers. While all included papers focus on applying Reinforcement Learning algorithms within the Public Goods Game, their specific objectives differ.

Table 1. Topics identified in the retrieved literature.

	Topic
1	Learning, conditional cooperation, and fairness
2	Punishment and sanction mechanisms
3	Agent-based social networks and complex structures
4	Moral learning, cognitive aspects, and cooperative AI
5	Cooperation under uncertainty and collective risk
6	Dynamic multi-objective learning, cooperation and imitation in multiplayer scenarios

Source: Authors' own elaboration.

The first topic identified, i.e., “Learning, conditional cooperation and fairness”, encompasses all work investigating how Reinforcement Learning fosters cooperative learning and induces fairness behaviour among agents. The included studies examine the impact of memory and strategy adaptation during recurrent interactions on agents' propensity to engage in cooperative behaviour. From a general perspective, conditional learning represents a key dynamic that enhances cooperation. This is evidenced by the fact that agents modulate their contributions to the common fund in response to each other's behaviour, thus promoting shared fairness. The second topic, i.e., “Punishment and sanction mechanisms”, comprises all works that analyse the impact of punishment and sanction mechanisms on cooperation in the public goods game. The studies in this review suggest that implementing altruistic punishments and decentralised sanctions would discourage free-riding opportunistic behaviour, stabilising cooperation in the long run. In particular, implementing punitive measures reinforces the adherence to cooperative norms within social groups, thereby reducing the incidence of free-riding behaviour. The third topic, i.e., “Agent-based social networks and complex structures”, incorporates all research that examines the function of agent-based social networks and complex structures in facilitating cooperation. In this context, simulations utilising multi-agent models

demonstrate the impact of large-scale interactions and network dynamics on the level of cooperation observed in the Public Goods Game. As has been observed, the applications of this approach span a range of fields, from urban resource management to efficient communication in complex networks. This illustrates the crucial role of social network structure in supporting cooperative behaviour.

The fourth topic, i.e., “Moral learning, cognitive aspects and cooperative AI”, comprises papers that investigate the moral and cognitive underpinnings of cooperative learning through agent simulations. To clarify, incorporating moral values and social norms in Reinforcement Learning permits agents to learn to cooperate, even in the presence of inequalities (e.g. as in the case of resource inequalities in the Public Goods Game). Cognitive dynamics, such as inequity aversion and perceived fairness, emerge as mechanisms that incentivise cooperation by balancing immediate benefits against future benefits. The fifth topic, i.e., “Cooperation under uncertainty and collective risk”, consists of all papers that investigate the cooperative behaviour of agents under conditions of uncertainty and collective risk. The included studies demonstrate that agents can adapt their strategies under the perceived risk and the collective resources at their disposal. It can thus be concluded that learning models help understand agents' strategic decisions, particularly in fostering cooperation through awareness of shared risks and adopting strategies to mitigate them.

The sixth topic, i.e., “Dynamic multi-objective learning, cooperation and imitation in multiplayer scenarios”, comprises papers that aim to investigate how agents learn in different multi-objective learning scenarios, thereby shedding light on the dynamics of cooperation in multiplayer contexts. Collectively, these studies demonstrate that imitation strategies and adaptive learning models facilitate the establishment of sustainable cooperative behaviour. In scenarios where cooperation is driven by dynamic rewards and shaped by social structures, agents pursue a balance between individual gain and collective benefit. Based on the previous considerations, the clusters of papers identified by topic are shown in Table 2. In detail, for each cluster (1,...,6), the authors and the year of publication of the respective papers are listed in ascending alphabetical order.

Table 2. Grouping of papers by identified topics.

	Cluster (topic)
Allen et al. (2018)	1
Amado et al. (2015)	1
Bogdan et al. (2023)	1
Bühren et al. (2023)	1
Czupryna et al. (2024)	1
Ezaki et al. (2016)	1
Godara et al. (2022)	1
Horita et al. (2017)	1
Khalvati et al. (2019)	1
Leimar & McNamara (2019)	1
Li & Hao (2019)	1
Liu & Li (2025)	1
Tomassini & Antonioni (2019)	1
Wang et al. (2024)	1
Zhang et al. (2024a)	1
Bayer et al. (2009)	2
Castañón et al. (2023)	2
de Jong & Tuyls (2011)	2
Ferraro & Vossler (2006)	2
Godara & Herminghaus (2023)	2
Halty et al. (2020)	2
Hicri & Kirman (2007)	2
Kořveková et al. (2021)	2
Villatoro et al. (2014)	2
Yaman et al. (2023)	2
Zhang et al. (2024b)	2
Bai et al. (2024)	3
Barfuss et al. (2020)	3
Bennati et al. (2018)	3
Domingos et al. (2021)	3
Du et al. (2024)	3
Grinberg & Todorov (2016)	3
Han et al. (2017)	3
Jäger & Reisinger (2022)	3
Jia et al. (2022)	3

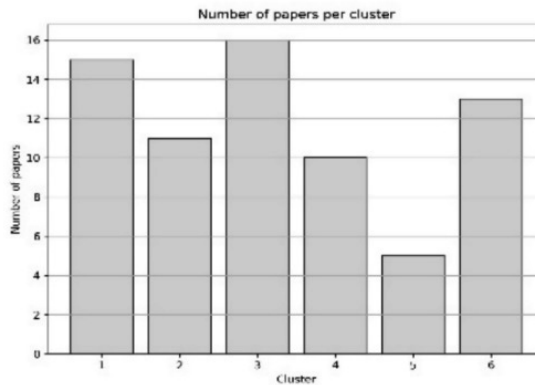
Table 2. Grouping of papers by identified topics (continud)

	Cluster (topic)
Klima et al. (2018)	3
Lindström & Tobler (2018)	3
Lugovskyy et al. (2017)	3
Santos et al. (2020)	3
Wu et al. (2018)	3
You et al. (2025)	3
Zou & Huang (2024)	3
Biele et al. (2008)	4
Cushman et al. (2017)	4
Hughes et al. (2018)	4
Koster et al. (2022)	4
López de Aberasturi Gómez et al. (2024)	4
ManChon & Zhen (2010)	4
Newton (2018)	4
Orzan et al. (2023)	4
Rusch et al. (2020)	4
Seymour et al. (2007)	4
Kumar & Dutt (2020)	5
Merhej et al. (2021)	5
Merhej et al. (2022)	5
Park et al. (2019)	5
Pereira & Santos (2019)	5
Christoforou et al. (2023)	6
Cooper & Stockman (2002)	6
Couto & Pal (2023)	6
Han et al. (2023)	6
Mak & Zwick (2010)	6
Odouard et al. (2023)	6
Orzan et al. (2024)	6
Pal & Sengupta (2022)	6
Salazar et al. (2022)	6
Shen et al. (2024)	6
Usvitskiy (2024)	6
Wang & Yang (2024)	6
Wang et al. (2023)	6

Source: Authors' own elaboration.

Examining the numerical distribution of papers in the different clusters is now appropriate. As illustrated in Figure 2, Cluster 3 appears to be the most populated, while Cluster 5 has the lowest number of publications. Furthermore, Clusters 1 and 6 demonstrate a notable consistency in contributions, with a relatively high number of publications compared to Clusters 2 and 4. In more detail, Cluster 1 contains 15 papers, Cluster 2 contains 11 papers, Cluster 3 consists of 16 papers, Cluster 4 contains 10 papers, Cluster 5 contains 5 papers and Cluster 6 contains 13 papers. A preliminary examination of the data reveals that most of the published works fall into the clusters “Agent-based social networks and complex structures” and “Learning, conditional cooperation and equity”. While these preliminary findings offer valuable insights into the most investigated research areas, it is equally important to conduct a more comprehensive analysis by examining the temporal evolution of publications. A temporal analysis will provide a more thorough representation of emerging trends and potential future research directions, facilitating a more nuanced understanding of the evolution of scientific interest over time and the emergence of new research topics.

Figure 2. Aggregate number of papers for each identified cluster.



Source: Authors' own elaboration.

Building on the above, Figure 3 illustrates the temporal distribution of papers for each cluster. The X-axis represents the year of publication, while

the Y-axis depicts the number of papers published each year. The legend defines the symbols used for each cluster, thus enabling the reader to distinguish between them within the graph. Specifically, it can be observed that Cluster 1 is characterised by a gradual increase in the number of publications since around 2010, with a notable surge between 2015 and 2020, reaching its peak around 2019. Subsequently, a modest decline is evident, with a reduction towards 2023.

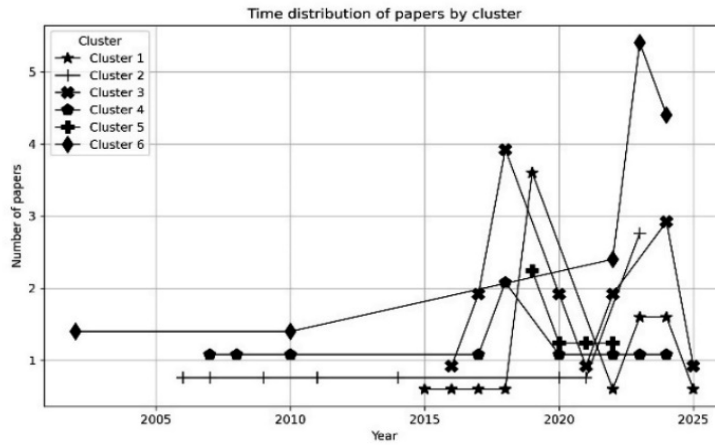
In summary, there was a discernible increase in interest in conditional cooperation and learning concepts during this period. Cluster 2 exhibits consistent publications from 2005 until approximately 2020 when a slight uptick is observed. However, despite the limited growth, the cluster never attains a significant peak and maintains a relatively flat trend with few publications per year on average, particularly during the initial 15-year period. Cluster 3 reveals an upward trajectory since 2015, with a notable increase in publications between 2018 and 2019. Subsequently, there is a decline, but scientific production remains active until 2023. This trend reflects the growing interest in analysing cooperation between agents through the lens of complex social networks and interactive structures. Additionally, it reflects the relatively recent emergence of this research field. The publications included in Cluster 4 were somewhat intermittent before 2015, with a moderate increase observed since that year. The graph illustrates that the cluster exhibits a pronounced peak around 2019-2020. This indicates that there has been a rapid increase in scientific interest in the moral and cognitive aspects of cooperative AI in recent years, which is likely to reflect the growing focus on the ethics of AI and moral learning.

With regard to Cluster 5, the number of papers published in this domain increased rapidly from 2014 until 2018. Following this period, there was a fluctuation, but the number of papers remained relatively high until 2022. This trend suggests that cooperation under uncertainty has emerged as a topic of great relevance in recent years, as collective risks (such as climate change) have become central to scientific debates.

Cluster 6 demonstrates a consistent upward trajectory, with a limited number of publications before 2015, followed by a pronounced peak in 2020. Following the peak, there is a slight decline, but the topic remains active until 2023. It can thus be concluded that dynamic learning and imitation are emerging topics, particularly in multiplayer scenarios. This

reflects the growing interest in more sophisticated and adaptive approaches to cooperation within the arena of the Public Goods Game.

Figure 3. Temporal distribution of papers by cluster.



Source: Authors' own elaboration.

5. Discussion and concluding remarks

The clustering study has revealed that the most populated clusters are those related to the topics of “Agent-based social networks and complex structures” and “Learning, conditional cooperation and fairness”. This finding indicates that the scientific community is highly interested in complex social structures and learning mechanisms that foster conditional cooperation, among other things. In this regard, multi-agent simulations and network models are proving to be effective tools for exploring large-scale cooperation, where interactions between agents follow evolutionary and adaptive dynamics. Another significantly populated cluster is that of “Dynamic multi-objective learning, cooperation and imitation in multiplayer scenarios”. This reflects the emergence of innovative techniques for studying cooperation in dynamic and complex contexts. It can be argued that an investigation into the strategies employed by agents to imitate and adapt their learning processes is paramount for understanding how agents achieve a balance between individual and collective goals.

The temporal analysis indicates that topics such as moral learning, cognitive aspects, cooperative AI, and cooperation under uncertainty and collective risk have become increasingly relevant, particularly following 2015. This may be attributed to the growing emphasis on AI ethics, moral learning, and the challenges associated with collective risks, such as climate change. The cluster entitled “Punishment and sanctioning mechanisms” demonstrated consistent temporal stability, indicating that altruistic punishment and sanctioning mechanisms remain pivotal in studying cooperative dynamics.

Overall, the pre-analytical investigation in this paper helped identify significant research trends and potential areas for further investigation within the existing literature. These include studies of agent interaction in contexts of high uncertainty and collective risk, as well as the deepening of cooperative and moral AI. Further investigation of these areas may facilitate the development of practical applications for use in complex decision-making contexts. The ongoing advancement of dynamic and multi-objective learning models, coupled with the utilisation of Reinforcement Learning in complex social networks, indicates that advanced simulation techniques and

adaptive learning approaches will persist in offering novel insights into cooperation and group dynamics.

In a nutshell, this study provided a first systematic overview of the existing literature on the application of Reinforcement Learning in the context of the Public Goods Game. The evidence from the literature review leads to the conclusion that the dynamics of cooperation between agents are complex phenomena studied from various interrelated perspectives. The analysis of the temporal evolution of the clusters revealed an increasing emphasis on moral learning, collective risk, and dynamic adaptation in multiplayer contexts. This suggests the emergence of key topics that are likely to exert a considerable influence on future research on cooperation and interactive agent learning. In conclusion, this study contributes to the existing literature on Reinforcement Learning that employs the Public Goods Game as a framework for exploring collective action problems, providing a guide for future research and practical applications in this field. Though our investigation includes works related to Reinforcement Learning, it does not comprehensively review all the experimental research in the AI field applied to cooperative settings. As such, future research could further investigate the role of IT artefacts in experimental studies and, hence, the relation between lab and extra lab experiments, which are seldom considered two sides of the same coin. From a methodological point of view, it will be worth analysing the algorithmic clustering approach in more detail to improve the interpretability and robustness of agent-based learning models in Reinforcement Learning.

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