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Innovation in times of financial crises

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Abstract

It is argued that productivity gains should be maintained during times of severe financial and economic crises so that the economy gets back on track and does not get trapped in a state of underperformance. Innovation is an important factor in productivity improvement. We use historical patent data going back to 1883 and standard economic indicators to investigate the impact of major crises on innovation. Data are drawn from the World Intellectual Property Organization on patents in the United States and patents are used as a proxy for innovation. We find that crisis spur innovation with the effect being noticeable for up to three years after the crisis. As a by-product of our analysis we provide empirical evidence that innovation has a positive effect on growth.

Keywords: Innovation, economic growth, economic crises, financial crises, patents, innovation lag.

Introduction

It is widely accepted, going back to the work of Schumpeter (1942), that “innovation is an engine that drives growth”. Innovations, be it new products and processes, or new legal and institutional environments for conducting business, are the inventions that can be applied successfully. Innovations bring about a positive change in terms of higher productivity. Hence, innovation is considered a major driver of economic development. On the other hand, innovations may have a destructive effect as new developments alter or obliterate old organizational practices, processes and products. Schumpeter coined the term “creative destruction” to describe the process through which innovation creates new markets while destroying old ones. As a consequence, systems that do not innovate effectively may be destroyed by those that do.

Because of the double-edged nature of the process of “creative destruction”, Schumpeter saw the process of innovation not only as a driving force for progress but also as a cause of recurring recessions and cyclical behavior of the economic development. In his work on business cycles, Schumpeter (1939) interprets the major waves of economic growth and technological transformation as “successive industrial revolutions” and explains that these clusters of radical innovations are dependent on financial capital. Perez (2002) recently developed this idea further, showing that technological revolutions arrive with some degree of regularity and that economies react to them in predictable phases. Like Schumpeter she believes that creation of the new technology corresponds to the period of explosive growth, and turbulence and uncertainty usually follow the revolutionary developments, leading to the collapse of bubbles created by financial speculation. Perez argues that the financial crises are a prelude to industrial shake-up and the shift to a new “paradigm”.

Each technological revolution is received as a shock and its diffusion encounters resistance both in the established institutions and the general population. Technological revolutions bring not only a full revamping of the productive structure but also the transformation of the institutions of governance, society and even of ideologies and culture. According to (Perez 2002), “creative destruction” occurs every 50-60 years both in the economy and socio-political framework.

A key question of particular interest during the current crisis is the role of innovation in stimulating a recovery. Countries like the USA and France, have taken a firm stance on investment in R&D as a major thrust of their efforts. The EU has increased its research budget by a significant 5% during the crisis. Other countries are still grappling with this issue, while smaller countries feel that investment in R&D will not have any impact on their economic recovery. As Pisani-Ferry and Pottelsberghe (2009) point out, national policies do matter in determining the recovery strategy. Comparing the examples of two countries, Sweden and Japan, they show that policies implemented during crisis and in response to it, have major bearing on long-term growth. Thus, Sweden was able to recoup its output loss entirely by using recession as an opportunity for economic transformation and investing heavily in R&D and education.

While there are arguments that innovation drives economic growth in post-industrial societies and while policy-makers argue that investments in R&D are essential for getting out of financial crises, there is no empirical evidence on what happens to innovation in times of economic crises. Surprisingly, there are very few empirical studies that link innovation with economic crises, with Filippetti and Archibugi (2011), Archibugi et al (2013) and Paunov (2012) being the exceptions. Using micro data Filippetti and Archibugi (2011) show that the effects of economic

downturn on innovation investment are not the same across European countries, and that structural factors such as quality of human resources, specialization in high-tech sectors and the development of financial system are able to offset the negative effects of economic downturn. Archibugi et al. (2013) analyze the investment decisions of firms before and during the crisis and find that companies that were highly innovative in the past, continued investments in R&D during the crisis. Paunov (2012) using survey data from Latin American firms during the 2008-2009 global crisis show that although the crises led many firms to stop innovation projects, firms with access to public funding were less likely to abandon investments in innovation. Although these studies provide valuable micro-economic view on the innovation strategies of firms in times of crises, the macro-economic picture is still lacking.

In this paper we investigate the bi-directional link between innovation and economic growth with particular attention to crises, as it is during crises that the Schumpeterian “creative destruction” takes place and it is major crises that signal a “paradigm shift” according to Perez (2002).

The paper is organized as follows: First, we present the basic model. Second, we describe the data used in our analysis. Third, we present the empirical test of the model. Finally, we draw conclusions and discuss questions for future research.

A model for linking innovation with economic growth

We describe the model that links innovation with economic growth, on which we base our empirical work. This is not a theoretical model in the sense of explaining, “how things happen”, but it looks at the macro-relations to explain “what happens”. Nevertheless, it is a theoretical model in the sense that it can be subjected to empirical testing for its verification or refutation. And while the arguments we use in developing this model are drawn from existing literature on innovation (for the debate between Shumpeterian evolutionary approach and neo-classical “endogenous growth theory” see Verspagen, 2005), it is its empirical verification that is conspicuously absent from literature and this is one contribution we first seek to provide, before we use the model to test for the effect of crises.

The relationships between the factors of the model are illustrated in Figure 1. At the top level we have Link no. 1 in which we are primarily interested: Innovation feeds into economic growth. However, innovation is also fed from economic growth as highlighted in the lower part of the figure. That is, economic growth leads to increases in education (Link no. 2), which leads into research and development (R&D, Link no. 3), which in turn leads to innovation (Link no. 4).

These links are derived from existing literature. Link no. 1 is the one we are testing empirically, and the literature has been discussed above, so we move to Link no. 2. By “education” we mean the general body of useful knowledge as articulated in Mokyr (2002) in his discussion of the historical origins of the knowledge economy. Mokyr (chapter 1) develops a *theory of useful knowledge*, which he classifies into *propositional knowledge*, or beliefs about natural phenomena and regularities, and *prescriptive knowledge*, also called techniques. The link of economic growth to the

generation of “useful knowledge” is discussed in passing in Mokyr, but is dealt with at length in Ruttan (2001), so Link no. 2 is derived from this literature.

Link no. 3 postulates a relation between education and R&D, where by this term we mean all the activities that go on in university research centers, government laboratories and the R&D division of enterprises. This link education-innovation is not strenuous, as argued in Mokyr (2002, chapter 6), however its nature is rather vague for now and we do not yet pursue in which ways education levels affect R&D. This vagueness is inconsequential for our model, since we might as well go straight from education to innovation without altering the basic hypotheses we are testing empirically later.

Link no. 4 describes the process through which R&D leads to innovations in products and processes. The process is well documented in the literature on entrepreneurship and incubators, knowledge regions, venture capital and the like (Becattini et al. 2009; Duranton et al. 2011; Casson et al. 2006; Alberti et al. 2008).

Another (recent) strand of literature argues that it is not necessarily technology that leads to innovation, but organizational structures and commercial processes, among others, can become important innovations (Hirsch-Kreinsen and Jacobson, 2008). For instance, traditionally low-tech textile industries also achieve growth in productivity and generate innovation, that may not be captured by the R&D data of these firms but instead draw heavily from related high-tech sectors.

We point out that the model describes a feedback loop and, hence, we need to establish in the empirical investigation whether the causality is from innovation to economic growth (Link no. 1) or economic growth feeds into innovation as illustrated with the aggregate Link no. 5 that bypasses the intermediate steps of education and

R&D. Since our objective is to identify if *financial crises have an effect* on the link between innovation and growth we test directly Links no. 1 and no. 5.

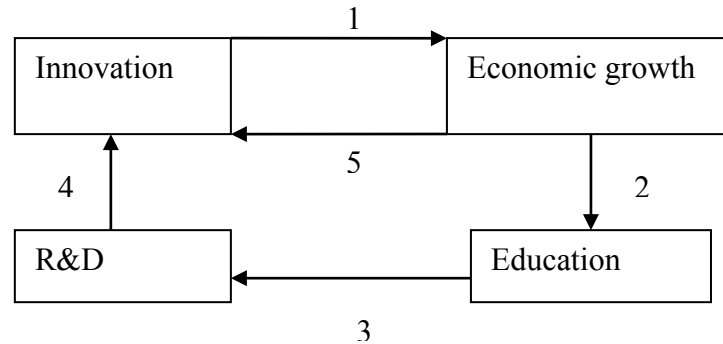


Figure 1: The feedback loop between innovation and economic growth.

We start with Link 1, investigating the effect of innovation on economic growth. According to the neoclassical growth model, economic development is a function of labor and physical capital (Solow 1956, 1957). In the original model Solow treated technological change as exogenous but Romer (1990) augmented Solow by treating technological change as an endogenous variable. In Romer’s model innovations are produced like any other goods using R&D labor as input. Romer’s model is well justified in the light of further work by (Freeman, 2008) who identified that “residual factors”, other than labor and capital, account for larger part of economic growth. The relationship between R&D and GDP was also estimated in the econometric models of Griliches (1979), where “knowledge stock” is added to the original factors of labor and capital in the production function.

To enhance understanding of what else influences economic growth, researchers augmented the model with additional exogenous and endogenous variables. Some of the examples include human capital (Mankiw et al. 1992, Islam 1995), trust (Dearmon and Grier, 2009) etc. The main critique of such models remains

the interdependence of the various factors involved, see Nelson (1973) and Verspagen (1992). To test the impact of innovation on economic growth we take the macroeconomic production function with capital stock, labor and education as main explanatory variables in a specification similar to Dearmon and Grier (2009).

Our base Model 1 is estimated by the following equation:

Model 1: $\ln(\text{GDPPC}) = \beta_0 + \beta_1 \ln(\text{Inv/GDP}) + \beta_2 \ln(\text{Labor}) + \beta_3 \ln(\text{Edu})$.

The following variables are used in the model: GDPPC is real GDP per-capita, Inv/GDP is investment share of real GDP, Labor is the total labor force, and Edu is the percentage of total population over 15 which have reached, or “attained”, the secondary education level.

Next we add innovation and economic crises to explanatory variables. We measure innovation by the number of patents. The Crises variable is obtained from the Reinhart and Rogoff dataset and counts the number of banking, debt or inflation crises and stock market crashes. It equals “0” in years with no crises, and takes the maximum of “3” in years that experienced three crises simultaneously, such as banking and debt and stock market.

The use of patents as a measure of innovative activity is recognized as an imperfect proxy, because not all inventions are patented and those patented greatly differ in quality. However, following Furman et al. (2002) and Trajtenberg (1990) we adopt the number of registered patents as “the only observable manifestation of inventive activity with a well-grounded claim from universality” (Trajtenberg 1990, 183). We use both the number of granted patents and patent applications to see if there is difference in the effect on economic growth. Adding financial crises to explanatory variables of Model 1 is a trivial addition in a sense, as crises are defined

as a significant drop of GDP for three consecutive quarters. However, we are interested to see whether there is a joint effect with innovation and also to check the directionality of the effect: financial crises should have a negative impact on economic growth; hence, the coefficient should be negative.

Model 2 is estimated by the following regression:

Model 2: $\ln(\text{GDPPC}) = \beta_0 + \beta_1 \ln(\text{Inv}/\text{GDP}) + \beta_2 \ln(\text{Labor}) + \beta_3 \ln(\text{Edu}) + \beta_4 \ln(\text{Patents}) + \beta_5 \text{Crises}$.

We now proceed with Link 5 to investigate the impact of economic growth on innovation. Our point of departure are the determinants of national innovative capacity investigated in Furman et al. (2002) and we use a similar base model in our study. This is Model 3 estimated by the following equation:

Model 3: $\ln(\text{Patents}) = \beta_0 + \beta_1 \ln(\text{GDPPC})$.

We now add crises to explanatory variables to obtain:

Model 4: $\ln(\text{Patents}) = \beta_0 + \beta_1 \ln(\text{GDPPC}) + \beta_2 \text{Crises}$.

Model 4 in particular will tell us whether financial crises spur innovation. As economies worldwide collapse and firms retrench, people look for alternatives: cheaper, faster or easier alternatives. Draper (2009) believes that recessions and crises give birth to some of the greatest, longest lasting and best-run companies of the world. For everyone it is a time of crisis, but for entrepreneurs this is a time of opportunities and our model tests empirically these arguments.

Empirical analysis and data description

In order to test now whether financial crises have an impact on innovation we proceed with the empirical testing of the following hypotheses on our data sets:

[H1] Innovation has a positive impact on economic growth

[H2a] Economic growth has a positive impact on innovation

[H2b] Financial crises spur innovation.

Of course the most interesting hypothesis where our contribution lies is in [H2b].

We use the following data: Penn World Tables-PWT (Heston et al. 2012), the Barro-Lee education dataset (Barro and Lee 2010) updated on April 9th 2013, the World development indication-WDI (World Bank 2012), the Reinhard and Rogoff (2009) list of financial crises, and the WIPO (World Intellectual Property Organization) data on patents. We use the WIPO data on the number of patents granted by the US patent office, as well as patent applications, covering the period from 1883 to 2012 for the second hypothesis and the period from 1950 to 2012 for the first hypothesis. (The use of different time periods is necessary for consistency among the databases we use, as explained below.) Variables from PWT dataset used in the regressions include real GDP per-capita and investment share of real GDP (Inv/GDP). The data on educational attainment from the Barro and Lee database are linearly interpolated for missing years. To test the first hypothesis we construct a dataset that includes observations from 1950 until 2012 since variables for Inv/GDP, labor and education are available only from 1950 onwards and this limits out dataset for the Models 1 and 2. To test the second hypothesis we rely on the larger dataset that

includes observations from 1883 until 2012 which also allows us to obtain reliable estimates for the impact of crises that are rare events.

Results

Per capita income regressions

We start with a calibration of the base model of gross domestic product per capita (GDPPC) as a function of the basic growth factors of capital, labor and education, and add innovation and crises as part of the remaining factors. To test the first hypothesis we run OLS regression with GDP per capita as a dependent variable and capital, labor and education as independent variables and then add innovation (measured as a number of granted patents or patent applications) and economic crises to the equation to see, whether those variables also contribute to economic growth. For our hypothesis not to be rejected, innovation should have a positive sign and crises should have negative sign.

The results of the regression are presented in the Table 1 where we observe that in Model 1 the coefficients of capital (Inv/GDP) and labor are positive and significant. Education in this model is not significant (similar results are obtained by Dearmon and Grier 2009).

In Models 2a and 2b we add innovation variable measured as the number of patent applications and granted patents, respectively, and crises variable. In both models innovation variables are positive and significant, thus providing empirical validation to the argument that innovation has a positive effect on economic growth. Crises variable is negative and significant in Model 2a, as expected, supporting the trivial argument that crises affect negatively economic growth (this is a consistency check of our calibration).

Table 1: Influence of innovation and crises on GDP per capita

GDP p.c.	Model 1	Model 2a	Model 2b
Intercept	-3.652*** (0.219)	-2.896*** (0.166)	-3.331*** (0.153)
Inv/GDP	0.408*** (0.054)	0.325*** (0.038)	0.299*** (0.038)
Labor	1.096*** (0.026)	0.884*** (0.030)	0.936*** (0.26)
Education	-0.023 (0.030)	0.108*** (0.024)	0.061*** (0.022)
Crises		-0.014** (0.007)	0.001 (0.005)
Patent applications		0.124*** (0.014)	
Granted patents			0.137*** (0.016)
	F=2025.736 Adj.R ² = 0.991 N=54	F=3006.381 Adj.R ² = 0.996 N=54	F=2944.812 Adj.R ² = 0.996 N=54

*** p < 0.01; ** p < 0.05; *p < 0.1; values in parentheses are standard errors.

Patents regressions

To test Model 3 we run OLS regression with innovation as a dependent variable and GDP per capita as an explanatory variable. We expect GDP to contribute positively to innovation. In Model 4 we further add crises variable and if crises spur innovation the coefficient should be positive and the variable should be significant. We test the above equations with innovation measured both as the number of granted patents and patent applications. The results are presented in the Table 2.

The results of Models 3a and 3b are consistent with our expectation that GDP per capita positively influences innovation; the variable is positive and highly significant. In Models 4a and 4b we add the crises variable and see that the coefficients of the crises variable are also positive and highly significant, thus confirming that crises do spur innovation.

Table 2: Impact of GDP per capita and crises on innovation

Innovation as dependent variable (measured as the number of granted patents)			Innovation as dependent variable (measured as the number of patent applications)	
	Model 3a	Model 4a	Model 3b	Model 4b
Intercept	4.178*** (0.323)	4.048*** (0.325)	4.253*** (0.755)	4.079*** (0.355)
GDP per capita	0.702*** (0.034)	0.708*** (0.034)	0.755*** (0.038)	0.764*** (0.037)
CRISES		0.078*** (0.030)		0.102*** (0.032)
	F=424.772 Adj.R ² = 0.768 N=128	F=221.925 Adj.R ² = 0.780 N=127	F=397.056 Adj.R ² = 0.756 N=128	F=214.909 Adj.R ² = 0.771 N=127

*** p < 0.01; ** p < 0.05; *p < 0.1; values in parentheses are standard errors.

Furthermore, we investigate the delay between the onset of a crisis and the innovative activity that follows. We expect that crises have a long-term effect on innovation and continue to influence innovation for a few years afterwards. Also it takes time for innovative activities to come to fruition and lead to patent application and the eventual granting of a patent and, therefore, the effect of crises should be observed for some time after the onset of the crisis. We proceed to test lag effects: we test whether crises in year t affects innovation in years t+1, t+2, t+3 etc. The results of the lags analysis are presented in the Table 3.

Crises coefficients are highly significant in Models 5a, 5b and Model 5c, which correspond to lags of 1 to 3 years. Past this time lag (Models 5d and 5e) the crises coefficients become insignificant. Hence, the empirical analysis supports the argument that crises are persistent in spurring innovation for up to three years after the onset of the crisis.

Table 3: Impact of GDP per capita and crises on lagged innovation.

Innovation as dependent variable (measured as the number of granted patents starting from 1883)					
	Model 5a 1-year lag	Model 5b 2-year lag	Model 5c 3-year lag	Model 5d 4-year lag	Model 5e 5-year lag
Intercept	3.929*** (0.326)	3.883*** (0.321)	3.889*** (0.319)	3.954*** (0.320)	3.991*** (0.314)
GDP p.c. from 1882	0.723*** (0.034)				
CRISES from 1882	0.081*** (0.030)				
GDP p.c. From 1881		0.729*** (0.033)			
CRISES From1881		0.086*** (0.030)			
GDP p.c. From 1880			0.730*** (0.033)		
CRISES From1880			0.730** (0.029)		
GDP p.c. From 1879				0.728*** (0.033)	
CRISES From1879				0.037 (0.030)	
GDP p.c. From 1878					0.728*** (0.033)
CRISES From1878					0.014 (0.029)
	F=229.214 Adj.R ² = 0.781 N=128	F=238.306 Adj.R ² = N=128	F=243.464 Adj.R ² = 0.791 N=128	F=245.236 Adj.R ² = N=128	F=258.790 Adj.R ² = 0.801 N=128

*** p < 0.01; ** p < 0.05; *p < 0.1; values in parentheses are standard errors.

Conclusions and future research

This paper contributes to our understanding of the macroeconomic consequences of innovation in times of crises. First, it provides empirical evidence on the bidirectional relationship between innovation and economic growth. The data provide support for hypotheses that have long been embedded in existing literature, although empirical verifications have been limited. Most importantly, however, we studied the impact of economic crises and provide empirical evidence that major economic crises positively affect innovation. When the economic crises are characterized by long duration and significant drop in the industrial output they seem to create opportunities to innovate. Our empirical work establishes that this process indeed operates but its mechanics should be investigated.

We have also established that the effect of a crisis on innovation is significant for up to three years. It is worth pointing out that studies of historical episodes of debt crises show that growth resumes three years after deleveraging starts. Also, industrial experience of recent banking crises show that GDP downturn lasts on average two years even as declining employment rates last on average four, see (Reinhart and Rogoff 2009, McKinsey 2010, Laeven and Valencia 2013, Zenios 2013). There appears to be a consistency here between the three-year cycle of recovery and the three-year effect of crises on innovation that is worth exploring.

Having tested our models (and underlying hypotheses) using US data there is need to carry out similar analysis for other countries. While the models we test may reflect prevailing economic theories, our empirical work is not testing a theory in a laboratory setting but is testing the theory as put in practice by policy-makers in response to crises. Hence, it is worth establishing if our findings have universal applicability. Furthermore, having ex post knowledge on which countries performed

well in recovering from crises we can draw some lessons on the process through which crises spur innovation to stimulate growth out of a crisis..

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