

# PROCESS INNOVATIONS AND FIRM PRODUCTIVITY GROWTH: DOES FIRM SIZE MATTER?\*

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## **Abstract**

This paper directly analyses the effect of process innovation on firm productivity growth, making an explicit consideration of the impact of firm size in the nature of this relationship. In particular, we analyse whether firm size conditions the life span of the impact of process innovations on productivity growth. Firm data are drawn from a Spanish survey of manufacturing firms over the period 1991-1998. We use a fully non-parametric methodology based on the concept of stochastic dominance. Results show that the implementation of process innovations leads to an extra productivity growth both for large and small firms. However, the life span of this extra productivity growth is longer for large than for small firms.

**Key words:** productivity and process innovation, stochastic dominance, non-parametric analysis, firm size.

**JEL classification:** C12; C14; D2; D24; L6; O3.

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## **1. Introduction.**

There is a large stream of literature analysing the impact of technological activities on productivity using firm level data (see Griliches 2000 for a survey). Most of this literature focuses on the effects of the investment input (the R&D investment) on productivity using production function models.

We can distinguish between two main branches within the production function approach. On the one hand, those based in the construction of a measure of cumulated research effort or “R&D capital” (obtained as a sum of past R&D expenditures) that is introduced as an additional input into the firms production function (see Griliches, 1980, 1986; Griliches and Mairesse, 1983, 1984, 1990; and Cuneo and Mairesse, 1984). On the other hand, there are studies that replacing levels by growth rates in the production function model analyse the effect of R&D intensity on productivity growth (see Mansfield, 1965; Clark and Griliches, 1984; Link, 1981a, 1981b, and Griliches 1986).

Most of these works suffer from some econometric problems. The main one is the endogeneity problem, that is, the possible existence of a double causality relationship between R&D expenditures and productivity: it could be both true that R&D investment increases productivity and that only the most productive firms are able to generate enough resources to invest in R&D. Máñez *et al.* (2005) focus on this endogeneity problem when analysing the link between productivity and R&D.

Furthermore, there are difficulties in measuring the cumulated research effort or “R&D capital”, as one should make assumptions about the relevant lag structure allowing the R&D process to affect productivity growth. The effect of R&D investment on productivity would not necessarily be immediate, as this investment may affect productivity with some delay. Griliches (1979) seminal work already noticed that the

relationship between “R&D capital” and productivity encompasses two different and complicated processes: (i) the link between R&D activities and the achievement of innovations and, (ii) the implementation of these innovations into the firms production processes.<sup>1</sup>

The aforementioned problems altogether with the recent availability of data related not only to the input side of the innovation process but also to the innovative output of R&D activities itself, have made possible to look directly at the impact of innovation output on productivity growth. As an example of this approach, we find Crepon *et al.* (1998), where the production function includes innovation output (patents per employee or the share of innovative sales) as a determinant of productivity growth. In this line, Verspagen (1999), Parisi *et al.* (2002) and Gu and Tang (2003) considering direct measures of innovation output (such as patents or process innovations) obtain that process innovations have a positive impact on productivity.

The purpose of this paper is to investigate directly the effects of process innovation on total factor productivity (TFP, hereafter) growth. First, the paper checks for the existence of differences in TFP between process innovating firms and non-process innovators using a sample of Spanish manufacturing firms for the period 1990-1998. Therefore, we add a new national perspective to the existing stream of empirical literature analysing the relationship between process innovation and productivity. Our second contribution is analysing whether process innovations actually enhance TFP growth and which is the life span of the effects of these process innovations on TFP growth. In our analysis, we will bear in mind that the nature of the process

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<sup>1</sup> The empirical studies that use R&D to measure innovation obtain mixed results. Whereas Mohnen, (1992), Baldwin and Sabourin (2001), and Bernstein (2002) do not find a statistically significant link between productivity and innovation; other studies such as Nadiri and Prucha (1990), Lichtenberg and Sigel (1991), Hall and Mairesse (1995), Mairesse and Hall (1996), Griliches (1998), Griliches and Mairesse (1998), Harhoff (1998), Klette and Johansen (1998) and Parisi (2001) do find a significant link between R&D and productivity.

innovations implemented by large and small firms (and so their effects on productivity) may differ and, thus we will perform the analysis separately for small and large firms.<sup>2</sup> The third contribution of this paper is the use of a fully non-parametric methodology. Unlike other previous econometric works, we compare the entire distribution of TFP in levels (or growth) of process innovators and non-process innovators. More specifically, we compare the cumulative distribution functions of TFP in levels (or growth) of these two groups of firms. To rank these distributions we apply the concept of stochastic dominance and their differences are formally tested using the Kolmogorov-Smirnov (KS) one and two-sided tests.<sup>3</sup>

To the best of our knowledge, another paper that analyses the life span of the effects of process innovation on productivity growth is Jaumandreu and Huergo (2003). However, this work does not take into account that the nature of the relationship between process innovations and productivity growth may differ depending on whether one considers small or large firms. Further, there are other two important features that differentiate our paper from theirs: first, whereas we use a fully non-parametric method based on stochastic dominance techniques, they use a semi-parametric method; and secondly, they measure TFP growth by means of the (cost-shared based) Solow residual whereas we use a TFP index that is an extension of Caves *et al.* (1982) index.

Our empirical results confirm higher productivity levels for the firms implementing process innovations in a given year than for the firms not implementing them. Furthermore, our estimates also shed light on the importance of considering differences in firm size when analysing the relationship between process innovation

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<sup>2</sup> Using the classification of the survey used for the analysis (*Encuesta sobre estrategias empresariales*), we will classify as large firms those with more than 200 employees and as small firms those between 10 and 200 employees.

<sup>3</sup> This methodology has been previously used in this literature in Máñez *et al.* (2005), to analyse the relationship between R&D activities and productivity. It was also used by Delgado *et al.* (2002) to analyse the relationship between firm productivity and exports.

and productivity growth. For small firms, the implementation of a process innovation produces a contemporaneous extra-productivity growth that only lasts the mere year of the implementation. Nevertheless, for large firms the life span of extra productivity growth produced by the implementation of a process innovation is longer, as it lasts the implementation year itself plus an additional two-year period.

The rest of the paper is organized as follows. Section 2 summarizes the theoretical grounds in the relationship process innovation-productivity and the main hypotheses to test in this paper. Section 3 illustrates the stochastic dominance and testing procedures. Section 4 deals with the dataset. Section 5 is devoted to explain the TFP measure. Section 6 presents the empirical results and, lastly, section 7 concludes.

## **2. Process innovation and productivity.**

The link between process innovation and productivity has, at least, two theoretical supports. The first can be found in the *R&D capital stock model* (Griliches, 1979) already outlined in the introduction.

The second is found in Ericson and Pakes (1992, 1995) and Pakes and Ericson (1998) *active learning models*, where it is clearly stated that investments such as R&D, if successful, contribute to meliorate the efficiency or productivity parameter of the firm along time. If a firm R&D activities successful output is the production of a process innovation and this is actually implemented, we expect a growth in the productivity of such a firm. Therefore, in the *active learning models* the relationship between R&D activities and productivity growth passes through the achievement and implementation of process innovations. As already mentioned in the introduction, we focus our analysis on the link between the implementation of process innovations and the patterns of productivity growth.

However, it should be pointed out that the type of R&D performed by large and small firms differs and so thus the nature of their process innovations. Evidently, the

nature of the process innovations will have a significant influence on the pattern and life span of the productivity growth they produce. According to Baldwin (1997) small firms R&D is generally aimed to solve production problems and to profit from market opportunities when they appear. Therefore, this R&D will very likely produce incremental process innovations that become rapidly available (and can be implemented) at a low cost for all firms in the industry. Therefore, in this case, we expect the life span of the extra productivity growth produced by the implementation of a process innovation to be of short duration. However, large firms that undertake regularly R&D activities will introduce more complex process innovations that are more costly to imitate. Hence, we hypothesize that the life span of the extra-productivity growth produced by the implementation of a process innovation will be longer than that for small firms.

The previous theoretical arguments suggest organising our empirical work testing the following hypotheses using the concept of stochastic dominance:

- (i) If process innovations have a positive impact on productivity, the productivity distribution of process innovators in year  $t$  should dominate the productivity distribution of non-process innovators in  $t$ .
- (ii) If process innovations foster productivity growth the productivity growth distribution of first time innovators should dominate the productivity growth of non-process innovators (divergence hypothesis).
- (iii) The life span of the effect of process innovations implemented by large firms should be longer than the life span corresponding to process innovations implemented by small firms.

## 2. Methodology.

For the analysis of the hypothesis presented above, we use the concept of first order stochastic dominance which allows comparing and ranking the distributions of firm productivity for firms with different innovation trajectories.

To define the methodology let us assume that we have two independent and random productivity samples,  $z_1, \dots, z_n$  and  $z_{n+1}, \dots, z_{n+m}$ , with sizes  $n$  and  $m$ , drawn from the cumulative distribution functions  $F(\cdot)$  and  $G(\cdot)$ , respectively, and corresponding to two comparison groups of firms with different innovation trajectories. First order stochastic dominance of  $F$  with respect to  $G$  is defined as  $F(z) - G(z) \leq 0$  uniformly in  $z \in \mathfrak{R}$ , with strict inequality for some  $z$ . Since this comparison considers all moments of the distribution it is a stronger test of productivity differences between groups of firms than just comparing mean/median levels of productivity.

To undertake the stochastic dominance analysis proposed in this study we follow Delgado *et al.* (2002) and apply the one-sided and two sided Kolmogorov-Smirnov (KS) tests:

1. The two-sided test checks the hypothesis of equality of the two distributions, and the null can be expressed as:

$$H_0: F(z) - G(z) = 0 \quad \forall z \in \mathfrak{R} \text{ vs. } H_1: F(z) - G(z) \neq 0 \text{ for some } z \in \mathfrak{R} \quad (1)$$

2. The one-sided test checks for the sign of the difference between the two distributions, and can be expressed as:

$$H_0: F(z) - G(z) \leq 0 \quad \forall z \in \mathfrak{R} \text{ vs. } H_1: F(z) - G(z) > 0 \text{ for some } z \in \mathfrak{R} \quad (2)$$

These tests can also be formulated as follows:

1.  $H_0: \sup_{z \in \mathfrak{R}} |F(z) - G(z)| = 0$  vs.  $H_1: \sup_{z \in \mathfrak{R}} |F(z) - G(z)| \neq 0$  (3)

2.  $H_0: \sup_{z \in \mathfrak{R}} \{F(z) - G(z)\} = 0$  vs.  $H_1: \sup_{z \in \mathfrak{R}} \{F(z) - G(z)\} > 0$  (4)

The two-sided test indicates whether the two distributions are significantly different whereas the one-sided test allows to determine which distribution dominates

the other. Thus, if we reject the null hypothesis for the two sided test and do not reject the null for the one sided test, we can conclude that  $F$  stochastically dominates  $G$ .

The KS statistics to evaluate the two-sided and one-sided tests are, respectively

$$\mathbf{d}_{(n+m)} = \sqrt{\frac{n \cdot m}{n+m}} \max_{1 \leq i \leq (n+m)} |F_n(z_i) - G_m(z_i)| \quad (5)$$

$$\mathbf{h}_{(n+m)} = \sqrt{\frac{n \cdot m}{n+m}} \max_{1 \leq i \leq (n+m)} \{F_n(z_i) - G_m(z_i)\}, \quad (6)$$

where  $F_n$  and  $G_m$  are the empirical distribution functions of  $F$  and  $G$ , respectively. The corresponding  $p$ -values for these statistics are obtained through the evaluation of its asymptotic distributions under the assumption of independent observations. Kolmogorov (1933) and Smirnov (1939) show that under the null these asymptotic distributions are:<sup>4</sup>

$$\lim_{(n+m) \rightarrow \infty} \Pr(\mathbf{d}_{(n+m)} > v) = -2 \sum_{k=1}^{\infty} (-1)^k \exp(-2k^2 v^2) \quad (7)$$

$$\lim_{(n+m) \rightarrow \infty} \Pr(\mathbf{h}_{(n+m)} > v) = \exp(-2v^2) \quad (8)$$

The stochastic dominance methodology has a graphical interpretation that will be used in the results section. To describe it, let us assume that we want to compare TFP distributions between firms that obtain process innovations,  $F(z)$ , and firms that do not obtain them,  $G(z)$ . We say that  $F(z)$  dominates  $G(z)$  if  $F(z)$  is located to the right of  $G(z)$  in a graph where we represent productivity in the horizontal axis and cumulated probability in the vertical axis. The distribution functions represented in the graphs bellow are non-parametrically estimated using *kernel* densities (see Appendix A).

#### 4. The data.

The data used in this paper are drawn from the *Encuesta sobre Estrategias Empresariales* (ESEE, hereafter), an annual survey that is representative of Spanish

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<sup>4</sup> The  $p$ -values for the two-sided test are calculated using the first five terms in expression (7).

manufacturing firms classified by industrial sectors and size categories and that provides exhaustive information at the firm level.

The sampling procedure of the ESEE is the following. Firms with less than 10 employees are excluded from the survey. Firms with 10 to 200 employees were randomly sampled by industry and size strata, holding around a 5% of the population in 1990. All firms with more than 200 employees were requested to participate, obtaining a participation rate around 70% in 1990. Important efforts have been made to minimise attrition and to annually incorporate new firms with the same sampling criteria as in the base year so that the sample of firms remains representative of the Spanish manufacturing sector over time.<sup>5</sup> The total sample corresponding to the period 1991-1998, is made up of 13912 observations: 8934 observations belonging to small firms (those with 10 to 200 employees) and 4978 belonging to large firms (those with more than 200 employees). This means an annual average of 1739 firms, from which 64% (1117) are small firms and 36% (622) large firms.

The panel structure of the dataset allows classifying firms according to their process innovative activities across time. The specific question we use from the questionnaire to classify firms as process innovators or non-process innovators is the following. Firms are asked if they have introduced during the current year any important modification in the production process (process innovation).<sup>6,7</sup> However, to apply the KS tests we need that the firm reports information both on the process innovation question and on all the variables involved in the construction of the TFP measure. Applying this criterion we end up with a sample of 6637 small firms and 2270 large firms (see Table 1).

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<sup>5</sup> See <http://www.funep.es> for further details.

<sup>6</sup> The particular question in the survey is as follows: "Indicate if during 199X the firm introduced some important modification of the productive process (process innovation). If yes, indicate the materialization type (introduction of new machines, introduction of new methods of production organization, or both)".

<sup>7</sup> As pointed out by Huergo and Jaumandreu (2004), the question related to process innovations is likely to capture precisely what firms consider major innovative changes in their production process and the frequency of these changes as the question belongs to a section in which the firms has to answer to other R&D and innovation-related questions and is appropriately separated from other sections on questions about technology adoption and usage.

Further, in our observation window we consider that a firm is a first process innovating firm if not having obtained a process innovation up to period  $t$  obtains a process innovation in that period.

Finally, a proper application of the KS tests using panel data requires independence of observations both between the samples under comparison and among the observations of a given sample. Thus, in the design of the KS tests carried out in this paper we take into account this aspect of the methodology.

## 5. The measurement of productivity.

In this work we use total factor productivity (TFP) as the measure of productivity. TFP calculated at the firm level is measured by a multilateral productivity index that is an extension of the Caves *et al.* (1982) index, to account for the fact that firms with different sizes are differently sampled in the data set. This extension was developed in Good *et al.* (1996) and in Delgado *et al.* (2002).

In order to calculate TFP we define the following dummy variables,

$$p_{ft} = \begin{cases} 1 & \text{if firm } f \text{ belongs to size group } t \\ 0 & \text{otherwise} \end{cases}$$

$$j_{fs} = \begin{cases} 1 & \text{if firm } f \text{ belongs to industrial sector } s \text{ (s=1,...,18, NACE-CLIO R-25)} \\ 0 & \text{otherwise} \end{cases}$$

Having a sample of  $N$  firms ( $f=1,\dots,N$ ) for  $T$  years ( $t=1,\dots,T$ ), and assuming that observations from different firms are independent, one can calculate the TFP index for firm  $f$  belonging to size group  $t$  and to industry  $s$  in year  $t$ , with the following expression:

$$z_{fst} = \ln Y_{fst} - \overline{\ln Y_{ts}} - \frac{1}{2} \sum_{i=1}^I (\mathbf{v}_{fst}^i + \overline{\mathbf{v}_{ts}^i}) (\ln X_{fst}^i - \overline{\ln X_{ts}^i}) + \overline{\ln Y_{ts}} - \overline{\ln Y_s} - \frac{1}{2} \sum_{i=1}^I (\overline{\mathbf{v}_{st}^i} + \overline{\mathbf{v}_s^i}) (\overline{\ln X_{st}^i} - \overline{\ln X_s^i}), \quad (9)$$

where  $Y_{f\mathfrak{z}t}$  is the production of firm  $f$  belonging to industry  $s$  with size  $\mathfrak{t}$  in year  $t$ ,

$\mathbf{v}_{f\mathfrak{z}t}^i$  is the cost share of input  $i$  ( $i=1, \dots, J$ ) and  $X_{f\mathfrak{z}t}^i$  is the quantity of input  $i$  used.

Appendix B describes the process to calculate the series for capital, labour, intermediate goods used in production and production. Finally, we define

$$\overline{m}_{st} = \frac{1}{NT} \sum_{f=1}^N \sum_{t=1}^T m_{fstt} p_{ft} j_{fs} \text{ and } \overline{m}_s = \frac{1}{NT} \sum_{f=1}^N \sum_{t=1}^T m_{f\mathfrak{z}t} j_{fs}, \text{ where } m_{f\mathfrak{z}t} \text{ is alternatively}$$

$$\ln Y_{f\mathfrak{z}t}, \mathbf{v}_{fstt}^i \text{ or } \ln X_{fstt}^i.$$

The above index measures the TFP proportional difference of a firm  $f$  from industry  $s$  and size  $\mathfrak{t}$  in year  $t$  in relation with a reference firm. The reference firm varies according to industry. For industry  $s$ , in particular, it is defined as that firm whose outputs and inputs are equal to the geometric mean of the outputs and inputs of those firms that belong to industry  $s$  across all sample period and, also, as that firm whose input shares are equal to the arithmetic mean of the input shares of the firms belonging to industry  $s$  during all sample period.

The first component of this index (the three first terms of 9), compares the output and the use of inputs for each of the firms in period  $t$  with those of the mean of firms belonging to the same industry and size group, across time. This allows for transitivity in the comparisons across firms belonging to the same size group. The second component (three last terms in expression 9), preserves transitivity in the comparisons between firms belonging to the same industry but in different size groups. This second term measures the difference between productivity of a mean firm from a determined industry and size group, and productivity in the reference firm. Being the reference firm the mean firm of all belonging to the same industry (regardless its size). Finally, as we consider a different reference firm across industries we eliminate possible differences in productivity across industries, which will also allow considering jointly firms belonging to different industries.

## 6. Empirical results.

### 6.1. Process innovations and productivity.

To analyse whether firms that eventually introduce process innovations have higher productivity than firms that do not obtain them we compare, for every year, the productivity distribution functions of the “process innovating firms in  $t$ ” and of the “non-process innovating firms in  $t$ ”. A “process innovating firm in  $t$ ” is a firm that succeeded in obtaining a process innovation in  $t$ , whereas a “non-process innovating firm in  $t$ ” is a firm that has not obtained such an innovation in  $t$ .

Figure 1 shows the relative productivity distribution of process innovators and non-process innovators for all years of the period 1990-1998 (both for small and large firms).<sup>8</sup> These figures represent the equivalence between each of the quantiles of the productivity distribution for the “process innovators” in the quantiles scale of the productivity distribution for the “non-process innovators”. The diagonal represents the uniform distribution  $[0,1]$ , i.e. the relative distribution if both distributions were identical. The position of the relative distribution below the diagonal suggests that the distribution represented in the vertical axis stochastically dominates the distribution in the horizontal axis.

Looking at the figure we can conclude that for the small firms group the relative productivity distributions for the process innovating firms are below the diagonal for all years analysed (except for 1997, for which the distribution is partly above the diagonal), suggesting that the productivity distribution for process innovating firms stochastically dominates that for the non-process innovating firms. For the large firms group, the result is not so clearly defined as the relative distribution for 1992 and 1993 lies completely above the diagonal and for 1997 lies partly above the diagonal.

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<sup>8</sup> See Delgado *et al.* (2002) and Handcock and Morris (1999) for the technical details about relative distributions.

Therefore, we can not conclude that the productivity distribution for process innovators stochastically dominates that for the non-process innovators.

Given the observed differences, the next step is to formally test if the productivity distribution of process innovators stochastically dominates the productivity distribution of non-process innovators. Thus, for each time period and size group, we compare

$$F_t(z_t | \mathbf{t} = \mathbf{t}_0) \text{ vs. } G_t(z_t | \mathbf{t} = \mathbf{t}_0), \quad t = 1991, \dots, 1998; \quad \mathbf{t}_0 = l(\text{large}), s(\text{small})$$

using the one and two-sided tests defined in section 3, where  $F_t$  and  $G_t$  are the productivity distribution functions of process and non-process innovators, respectively.

Table 2 reports the results for the KS tests of productivity differentials between process and non-process innovators.<sup>9</sup> We carry out these tests separately for small and large firms. For the small firms group, we reject the null hypothesis of equality of the two distributions (at a 5% significance lever) for all years. Further, we can never reject the null that the productivity of process innovators is higher than that of non-process innovators. As for large firms, we only reject the null hypothesis of equality of the productivity distributions for three years of the sampling period (1995, 1996 and 1997). For these years we can not reject the null that the productivity for the process innovators is higher than that for the non-process innovators.

Therefore, we can infer two results from the previous KS tests: (i) the productivity distribution for small process innovators stochastically dominates the distribution for small non-process innovators and, (ii) for large firms the above conclusion only holds for three years (1995, 1996 and 1997).

## 6.2. *Analysing the divergence hypothesis.*

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<sup>9</sup> In these figures we also report the number of process innovators and the non-process innovators jointly with the empirical differences in the TFP for these two groups of firms.

In order to test the hypothesis of divergence in productivities between first time process innovators and non-process innovators, we follow a two step procedure. First, we compare the previous productivity distributions (in levels) of first-time process innovators and non-process innovators. Secondly, we compare the *ex-post* productivity growth distribution of first-time process innovators and non-process innovators. We need to carry out this two-step procedure as only if the previous productivity level of first-time process innovators is not lower than that of non-process innovators, higher *ex-post* productivity growth by first-time process innovators (in comparison to non-process innovators) will produce divergence between the *ex-post* productivities of innovators and non-innovators.

### 6.2.1. Comparing productivity levels previous to the introduction of process innovations.

In order to know which is the relative productivity level of the firms introducing a process innovation in  $t$  with respect to the firms that do not introduce it, we compare productivity distributions of two groups of firms: non-process innovators and first-time process innovators. First-time process innovators in  $t$  include those firms that obtain a process innovation for the first time (in our sample) in year  $t$ . Non-process innovation firms in  $t$  are those that not having obtained a process innovation until  $t$  do not obtain an innovation in  $t$  either.

Therefore, to know about the relative productivity levels of these two groups of firms, we should compare

$$F_{t-1}(z_{t-1} | \mathbf{t} = \mathbf{t}_0) \text{ vs. } G_{t-1}(z_{t-1} | \mathbf{t} = \mathbf{t}_0), \quad t = 1992, \dots, 1998; \quad \mathbf{t}_0 = l, s$$

where  $F_{t-1}$  and  $G_{t-1}$  are the previous year productivity distribution functions for first-time process innovators in  $t$  and non-process innovators in  $t$ , respectively.

Table 3 reports the size of the first-time process innovators cohorts between 1992 and 1998. The small size of these cohorts suggests not carrying out year-by-year KS tests comparing the productivity levels distribution of first-time process innovators

and non-process innovators as their results would be scarcely reliable. To overcome this limitation we apply this test jointly for the whole sample period. Therefore, we compare

$$F_{91,\dots,97}(z_{91,\dots,97} | \mathbf{t} = \mathbf{t}_0) \text{ vs. } G_{91,\dots,97}(\bar{z}_{91,\dots,97} | \mathbf{t} = \mathbf{t}_0), \quad \mathbf{t}_0 = l, s$$

where  $F_{91,\dots,97}$  and  $G_{91,\dots,97}$  are two productivity distribution functions that correspond to the period 1991-1997.  $F_{91,\dots,97}$  is the previous productivity distribution of first-time process innovators (including seven cohorts of first-time process innovators) and  $G_{91,\dots,97}$  is the average productivity distribution over the period 1991-1997 for the non-process innovators (firms that never obtain process innovations along the sample period).

To get the previous productivity distribution function for the first-time process innovators we follow two alternative approaches. In the first one, this distribution consists of the productivities in  $t - 1$  of the first-time innovators in  $t$  for  $t = 1992, \dots, 1998$ . In the second one, we build this distribution with the previous average productivity of the first-time process innovators in  $t$ , starting from the first year they are observed in the sample until  $t - 1$ . Whereas in the first approach we just consider the productivity of first-time process innovators in the year previous to implement its first process innovation; in the second approach, we use the average as a measure summarising their productivities along a longer period of time.

Figures 2 to 5 show the kernel estimates of the cumulative productivity distribution functions for first-time process innovators and non-process innovators. Independently of both the approach used to calculate the previous productivity distribution of first-time process innovators and the size group considered, in general, the distribution position of first-time process innovators is to the right of the position of non-innovators, indicating that firms that eventually introduce process innovations had previously higher productivity levels than non-process innovators. To examine

more formally this difference, we apply the one and two-sided KS tests to check whether the previous productivity level distribution of first-time process innovators stochastically dominates the productivity distribution of non-process innovators.

Table 4 reports tests statistics on the comparison of both distributions using the two approaches described above to calculate the previous productivity value for the first-time process innovators. Regardless the approach used to calculate the previous productivity of first-time process innovators and the size group considered: (i) we always reject the null hypothesis of equality of the productivity distributions; and (ii) the null hypothesis of favourable differences to first-time process innovators cannot be rejected at any reasonable significance level for both groups of firms. Thus, the results of the KS tests confirm that firms that eventually introduce process innovations enjoyed higher previous productivity levels than non-process innovators.

The observed difference in previous productivity in favour of first-time process innovators is very likely related to: (i) the sunk costs nature of R&D investments implies that only the most productive firms will invest in R&D (see the sample selection hypothesis in Máñez *et al.* 2005), and (ii) the need of performing R&D to obtain process innovations. The joint consideration of (i) and (ii) explains why first-time process innovators are previously more productive than non-process innovators.

### *6.2.2. Comparing the productivity growth of process innovators and non-process innovators.*

If process innovation fosters productivity growth (Griliches and Lichtenberg, 1984; Crepon *et al.*, 1998; Verspagen, 1999; Parisi *et al.*, 2002; Gu and Tang, 2003; and Huergo and Jaumandreu, 2004), the gap in productivity levels between process innovators and non-process innovators should increase after a firm implements a process innovation for the first time. The results obtained in the former section (higher previous productivity levels of first-time process innovators relative to non-process

innovators) ensure that if process innovations actually accelerate productivity growth we will observe a process of divergence between the productivity level of process innovators and non-process innovators.

To test whether process innovations foster productivity growth, we follow a two-stage procedure: first, we test whether the introduction of a process innovation has a contemporaneous effect on the productivity of the firm leading to some extra productivity growth; secondly, if we detect a contemporaneous effect of process innovation on productivity growth, we check further if this extra productivity growth persists across time.

To analyse if the introduction of a process innovation has an immediate effect on the productivity growth of the firm that introduces it, we examine whether or not productivity growth between  $t-1$  and  $t$  for first-time process innovators in  $t$  is greater than productivity growth of non-process innovators. Let  $F_{91,\dots,98}$  denote the productivity growth distribution between  $t-1$  and  $t$  of first-time process innovators in  $t$  and  $G_{91,\dots,98}$  the average year productivity growth distribution of non-innovators.<sup>10</sup> Therefore, the one and two-sided KS tests are applied to compare:

$$F_{91,\dots,98} \left( \mathcal{Z}_{t_f-1,t_f} \mid \mathbf{t} = \mathbf{t}_0 \right) \text{ vs. } G_{91,\dots,98} \left( \mathcal{Z}_{t_f-k_f,t_f} \mid \mathbf{t} = \mathbf{t}_0 \right), \mathbf{t}_0 = l, s; k_f = 1, \dots, 7; N \text{ firms } (f = 1, \dots, N)$$

Figures 6 and 7 report the estimates of these productivity growth distributions for first-time process innovators and non-process innovators for small and large firms, respectively. For both size groups, the position of the distribution of first-time process innovators is to the right of that of non-innovators except for the lower tail of the distribution (i.e. for negative values of the growth rate).

Further, the results of the KS tests reported in Table 5 suggest that for both size groups the productivity growth distribution of first-time process innovators from  $t-1$  to  $t$  (i.e. from the year previous to the introduction of the process innovation to the year

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<sup>10</sup> The cumulative yearly average growth rate is defined as:  $\mathcal{Z}_{t_f-k_f,t_f} = (z_{t_f} - z_{t_f-k_f})/k_f$ .

in which the innovation is implemented) stochastically dominates that of non-innovators since for both size groups: (i) we reject the null hypothesis of equality of the distributions (at the 1% significance level) and; (ii) we cannot reject the null of differences in productivity growth favourable to first time process innovators.

Therefore, we confirm that when a firm introduces for the first time a process innovation it has an immediate effect producing an extra productivity growth. As a result, the firm productivity growth from the year previous to the implementation of the innovation to the year in which it is implemented is faster than the productivity growth of the firms without process innovations. Huergo and Jaumandreu (2004) also obtain this contemporaneous effect of process innovation on productivity growth, although they do not distinguish between small and large firms.

The next question to analyse is whether this extra-productivity growth of first-time process innovators with respect to non-innovators persists across time. To compare the path of productivity growth of firms introducing a process innovation for the first time to that of non-process innovators, we follow a sequential approach: we examine from period to period whether or not the productivity growth distribution of first-time process innovators in  $t$  from  $t+k$  to  $t+k+1$  with  $k=0,\dots,7$  is greater than the productivity growth for non-innovators. This sequence goes on until we find that the productivity growth of first time process innovators from  $t+k$  to  $t+k+1$  converges to the productivity growth of non-process innovators. Therefore, we sequentially compare:

$$F_{91,\dots,98} \left( \mathcal{X}_{t_f+k_f, t_f+k_f+1} \mid \mathbf{t} = \mathbf{t}_0 \right) \text{ vs. } G_{91,\dots,98} \left( \mathcal{X}_{t_f-k_f, t_f} \mid \mathbf{t} = \mathbf{t}_0 \right),$$

$$\mathbf{t}_0 = l, s; t_f = 91, \dots, 98; k_f = 0, \dots, 7; N \text{ firms } (f = 1, \dots, N)$$

where  $F_{91,\dots,98}$  and  $G_{91,\dots,98}$  are two productivity growth distributions that correspond to the period 1991-1998.  $F_{91,\dots,98}$  is the productivity growth of first-time process innovators from  $t+k$  to  $t+k+1$  (including seven cohorts of first-time process innovators) and  $G_{91,\dots,98}$  is the average productivity growth distribution over the period 1991-1998 for the non-process innovators.

For small firms, Table 6 reports the tests that indicate that, independently of the period  $t+k$  to  $t+k+1$  considered, we cannot reject the null hypothesis of equality of the  $F_{91,\dots,98}$  and  $G_{91,\dots,98}$  distributions. Therefore, the productivity growth distribution of first-time process innovators in the years after the implementation of the innovation does not stochastically dominates that of non-innovators. It seems that the extra productivity growth enjoyed by first-time process innovators (with respect to non-process innovators) in the year of the introduction of the innovation rapidly ceases, as this extra productivity growth does not persist the years after the implementation (figures 8, 10 and 12 show that the relative position of the productivity growth distributions of first-time process innovators for  $t$ -( $t+1$ ), ( $t+1$ )-( $t+2$ ), or ( $t+2$ )-( $t+3$ ) is not always to the right of the productivity growth distribution of non-innovators).

For large firms we obtain different results (Table 6). The productivity growth distribution of first-time process innovators stochastically dominates that of non-innovators in the subperiods  $t$ -( $t+1$ ) and ( $t+1$ )-( $t+2$ ) since: (i) we reject the null of equality of productivity growth distributions of first-time process innovators and non-innovators for the subperiods  $t$ -( $t+1$ ) and ( $t+1$ )-( $t+2$ ), but not from subperiod ( $t+2$ )-( $t+3$ ) onwards;<sup>11</sup> and (ii) for the subperiods  $t$ -( $t+1$ ) and ( $t+1$ )-( $t+2$ ) we cannot reject the null hypothesis of differences in productivity growth in favour of first time process innovators (figures 9 and 11 show that the relative position of the productivity growth distributions of first-time process innovators for  $t$ -( $t+1$ ) and ( $t+1$ )-( $t+2$ ) subperiods, is generally, to the right of the productivity growth distribution of non-innovators). Thus, for large firms the extra-growth in productivity produced by the implementation of a first process innovation lasts longer than the mere year of the implementation and it persists for two years after this. Huergo and Jaumandreu (2004) using semi-parametric techniques and without considering the distinction between large and

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<sup>11</sup>As shown in Table 6, to check for the robustness of our results we also test whether we reject the null of equality of the growth distributions of first time process innovators and non-process innovators for the subperiod ( $t+3$ )-( $t+4$ ). The results of the two-sided KS indicate that we cannot reject the null of equality.

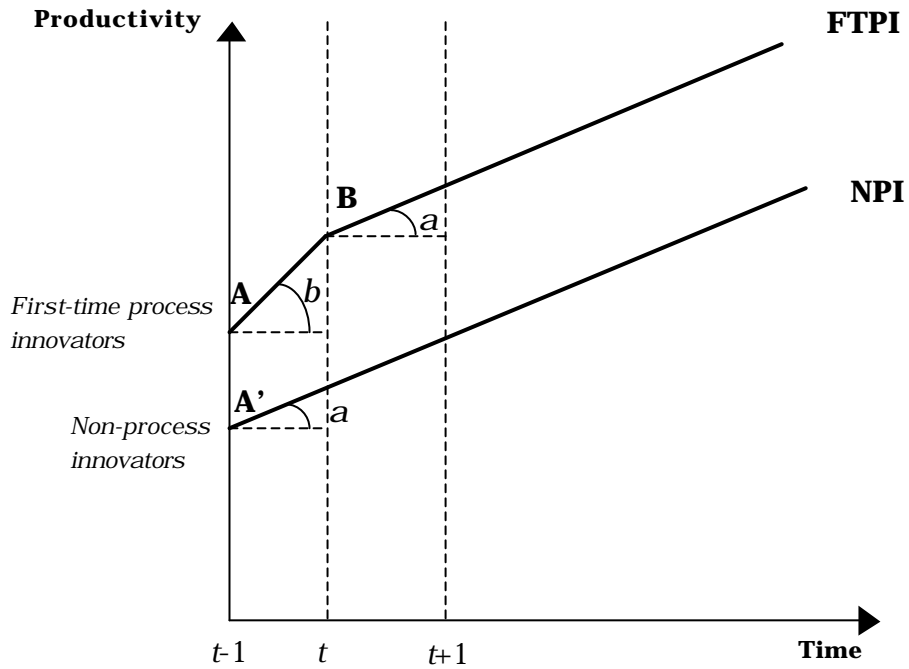
small firms obtain that the extra-productivity growth enjoyed by process innovators lasts for three years after the implementation of the process innovation.

We can summarise the results obtained in the analysis of the divergence hypothesis for small and large firms (sections 6.2.1 and 6.2.2) using figures 14 and 15, respectively. In the vertical axis of these figures we represent firms' productivity and in the horizontal axis the sequence of time from  $t-1$  onwards. For both size groups the previous productivity level of firms that eventually introduce a process innovation is higher than the productivity of non-process innovators. As a result the intercept of the FTPI (first-time process innovators) line is higher than the one of the NPI (non-process innovators) line ( $A > A'$ ). Further, since both for small and large firms the productivity growth of first-time process innovators between  $t-1$  and  $t$  is greater than the productivity growth of non-innovators, for this time period the slope of the FTPI line ( $\beta$ ) is higher than the slope of the NPI line ( $\alpha$ ).

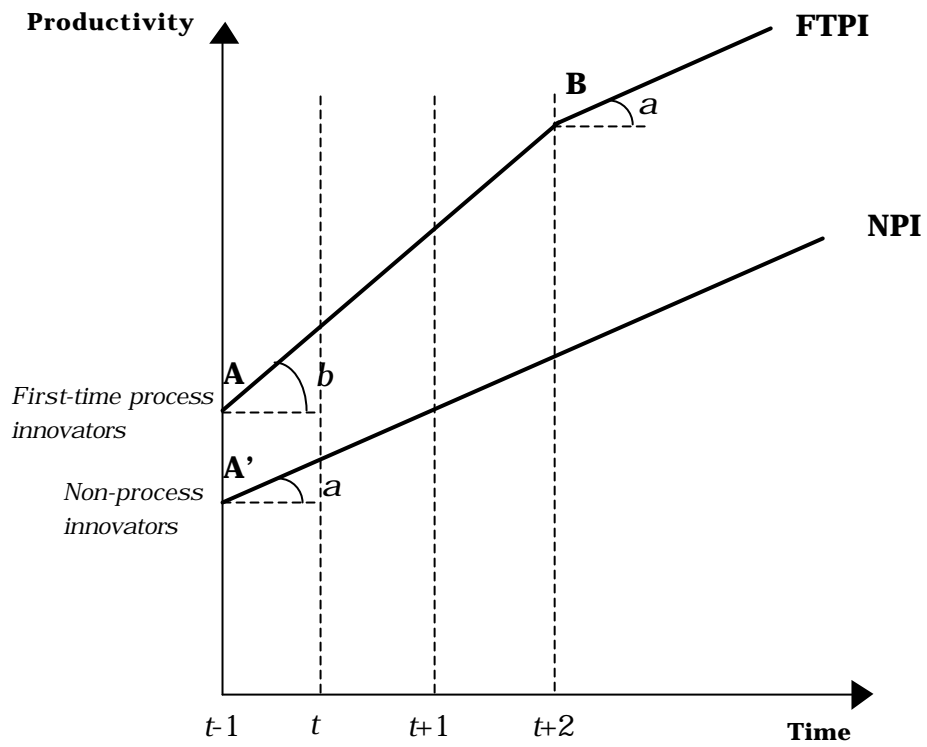
The difference between small and large firms arises from the different relative productivity growth of first-time process innovators with respect to non-process innovators after the year of implementation of the process innovation. For small firms, the extra-productivity growth produced by the implementation of a process innovation only lasts the period of the implementation. For the years after the implementation of the process innovation there is no difference between the productivity growth of first-time process innovators and non-innovators. Thus, from  $t$  onwards the slope of the FTPI line is identical to the slope of the NPI line ( $\alpha$ ).

For large firms, the extra-productivity growth produced by the introduction of a first process innovation persists until two years after its implementation. In figure 15, the slope of the FTPI for the sub-periods  $t-(t+1)$  and  $(t+1)-(t+2)$  ( $\beta$ ) is greater than the slope of the NPI line ( $\alpha$ ). However, after two years from the introduction of the process innovation the extra-productivity growth ceases, and so the slope of the FTPI and NPI lines ( $\alpha$ ) is the same.

**Figure 14: Small firms**



**Figure 15: Large firms**



Two questions arising from our results remain to be explained: first, why process innovation accelerates productivity growth during a number of years (one for small firms and three for large firms) but then productivity growth of innovators reverts to the one of non-innovators; and secondly, which are the factors explaining that the length of the period of extra-productivity growth of process innovators differs between large and small firms.

Let us start with the first question. Early introducers of successful process innovations will implement superior production methods that will proportionate them an extra-productivity growth with respect to other firms. However, according to Huergo and Jaumandreu (2004) firms average productivity is not just the result of the introduction of technological changes, it is a mix of incorporated technical change, learning-by-doing and absorption of spillovers. By absorption of spillovers, they mean the implementation of productive methods that are the results of others innovations and experience that have become “common knowledge”. Process innovators make the effort to create the new productive process that confers them temporary extra-productivity growth. However, since progressively these productive processes become “common knowledge” and are incorporated by every firm in the market, the path of productivity growth of innovators and non-innovators converges.

As for the second question, the difference in the duration of the persistence of the extra-productivity growth between small and large firms could be related to the different nature of the process innovations implemented by small and large firms. According to Baldwin (1997) small firms R&D is generally aimed to solve production problems and to profit from market opportunities when they appear. Therefore, this R&D very likely will produce incremental process innovations that become rapidly available (and can be implemented) at a low cost for all firms in the industry. This could explain why the extra-productivity growth of small first-time process innovators only lasts the period of the implementation of the innovation. However, large firms

that undertake regularly R&D activities will introduce more complex process innovations that are more costly to match and for which the period between their first implementation and the moment in which they become “common knowledge” is longer. This can explain why the extra-productivity growth get by a large first-time process innovator is not limited to the period of implementation and persists for two years after the implementation.

## **7. Concluding remarks.**

This paper has directly examined the effect of process innovations on productivity growth explicitly considering the impact that firm size has in this effect. Our main empirical results may be summarised in the following manner. First, for a given year, the productivity of firms that implement process innovations is larger than the productivity of non-process innovators suggesting that the implementation of process innovations increases productivity.

Secondly, previous productivity of firms that eventually introduce a process innovation is larger than the productivity of non-process innovators. This result is likely driven by the sunk nature of R&D investments that limits the access to R&D activities to the more productive firms, and also because performing R&D is usually a necessary condition to get process innovations.

Thirdly, independently of the size group considered the implementation of a process innovation by a first-time process innovator produces an extra-productivity growth for this firm (with respect to the productivity growth of non-process innovators). The joint consideration of the previous higher productivity of first-time process innovators and its higher rate of growth after the implementation of the innovation confirms the divergence hypothesis.

Fourthly, the life span of this extra-productivity growth differs between small and large firms. For small firms, the extra productivity growth is contemporaneous to the

implementation of the process innovation and its duration is limited to this period. The life span of the extra-productivity growth is longer for large firms. Since starting contemporaneously to the implementation of the process innovation it lasts two additional years. Probably, the main cause behind the different persistence of the extra-productivity growth for small and large firms lays in the nature of the process innovations they introduce. Small firms introduce incremental process innovations that can easily be copied by its competitors. Large firms introduce more complex process innovations that only become “common knowledge” with a longer delay. This delay gives large firms the possibility of enjoying higher productivity growth rates over a longer period of time.

Finally, the fact that the increase in productivity growth is contemporaneous to the implementation of the process innovation suggests that it is not just performing R&D activities but the implementation of a successful R&D result, as a process innovation, what fosters more immediately productivity growth. This could both explain the lack of significance of R&D investments as a determinant of productivity in some empirical works, and the need to introduce R&D lags to explain productivity.

## **Appendix A. Non-parametric estimation of distribution functions.**

A natural way to non-parametrically estimate the cumulative distribution function  $F$  consists of calculating

$$\hat{F}(z) = \int_{-\infty}^z \hat{f}(u) du$$

where  $\hat{f}$  is a non-parametric estimator of the probability density function obtained through de Kernel methodology. Where  $\hat{F}(z)$  is calculated,

$$\hat{F}(z) = \frac{1}{N} \sum_{i=1}^N K \left[ \frac{(z - x_i)}{h} \right]$$

in which  $K(u) = \int_{-\infty}^u k(\mathbf{n}) d\mathbf{n}$  is the Kernel cumulative distribution function,  $k(\mathbf{n})$ . In this work we have used a Gaussian kernel with the bandwidth parameter  $h = 0.9 \cdot A \cdot N^{-1/5}$ , with  $A = \text{minimum (standard deviation, interquartile rank/1.34)}$  estimated with that sample data.

## **Appendix B. Components to calculate the total factor productivity (TFP).**

To calculate the TFP index we need to construct the following variables:

*Output.* To obtain output we have adjusted sales by the net variation of existences from the firm balance. Output is calculated at constant prices of 1991 (first year of our sample) through firm specific deflators as we have both the information about the effective firm sale price for the product sold by the firm in each market in which it operates and the proportion of sales in each market over total firm sales.

*Labour.* Measured as the number of hours worked. This variable is calculated using the following information provided in our data set: number of part time and full time employees, the normal number of hours worked daily, the number of hours effectively worked and the number of hours lost during that year. The total hours worked is obtained multiplying the number of employees by the mean of hours worked during that year. To calculate the number of employees we have used information about the

number of both full and part-time workers reported at the end of the year and information about possible variations of the number of workers across each specific year.

*Other intermediate inputs.* These variables are defined as the sum of intermediate buys and external services contracted by the firm plus the stock variations. The adjustment of these variables to constant values has been done using firm specific deflators, calculated through the specific prices paid by the firm when acquiring any of these inputs (such as energy, raw materials, and other supplies and external services).

*Capital.* For the period 1993-1998 the capital stock has been approximated for each firm using the capital net value at replacement cost, calculating this as the gross capital at replacement cost minus the corresponding cumulated capital depreciation. For the period 1991-1992 we do not have enough information in the data set to use the above approximation. Thus, we calculate the capital stock using the permanent inventory from 1993 backwards. The permanent inventory formulae is:

$$KNR_t = I_t + KNR_{t-1} (1 - d_t) \frac{p_t}{p_{t-1}}$$

where  $KNR$  is net capital at replacement cost,  $I_t$  is investment in equipment,  $d_t$  is the equipment depreciation rate and  $p_t$  correspond to the equipment price indexes published by the Spanish National Statistics Institute (Instituto Nacional de Estadística).

*Input cost shares.* For each input, the cost share is the proportion that represents that input in the total cost of inputs. Where total cost is the sum of labour costs, intermediate inputs costs and the cost for capital. Labour costs are measured as the sum of wages paid, insurance and other labour costs paid by the firm. The cost of capital is calculated through the estimation of the user cost of capital, that is the cost for long run debts plus the depreciation rate ( $d_t$ ) minus the variation in the price index for capital goods.

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**Table 1. Number of firms and number of process innovating firms.**

| Years                  | Small firms |                    | Large firms |                    |
|------------------------|-------------|--------------------|-------------|--------------------|
|                        | Total       | Process innovators | Total       | Process innovators |
| 1991                   | 604         | 123                | 299         | 123                |
| 1992                   | 703         | 135                | 300         | 113                |
| 1993                   | 851         | 187                | 272         | 96                 |
| 1994                   | 842         | 181                | 287         | 108                |
| 1995                   | 820         | 173                | 310         | 125                |
| 1996                   | 864         | 161                | 266         | 106                |
| 1997                   | 992         | 231                | 275         | 112                |
| 1998                   | 961         | 243                | 261         | 114                |
| <b>Total 1991-1998</b> | 6637        | 1434               | 2270        | 897                |

**Table 2. Productivity differences between process innovators and non-process innovators**

| Year               | Number of observations |                        | Productivity differences | Equality of distributions |                 | Differences favourable to process innovators |                 |
|--------------------|------------------------|------------------------|--------------------------|---------------------------|-----------------|--|-----------------|
|                    | Process innovators     | Non-process innovators |                          | Statistic                 | <i>p</i> -value | Statistic                                    | <i>p</i> -value |
| <b>Small firms</b> |                        |                        |                          |                           |                 |  |                 |
| 1991               | 123                    | 481                    | 0.050                    | 1.346                     | 0.041           | 0.021  | 0.999           |
| 1992               | 135                    | 568                    | 0.053                    | 1.438                     | 0.024           | 0.204  | 0.920           |
| 1993               | 187                    | 664                    | 0.043                    | 1.411                     | 0.030           | 0.297  | 0.839           |
| 1994               | 181                    | 661                    | 0.048                    | 1.656                     | 0.006           | 0.225  | 0.903           |
| 1995               | 173                    | 647                    | 0.146                    | 2.694                     | 0.000           | 0.251  | 0.881           |
| 1996               | 161                    | 703                    | 0.061                    | 1.517                     | 0.015           | 0.235  | 0.896           |
| 1997               | 231                    | 761                    | 0.075                    | 2.228                     | 0.000           | 0.193  | 0.929           |
| 1998               | 243                    | 718                    | 0.068                    | 1.900                     | 0.001           | 0.094  | 0.983           |
| <b>Large firms</b> |                        |                        |                          |                           |                 |  |                 |
| 1991               | 123                    | 176                    | 0.000                    | 0.676                     | 0.704           | 0.599  | 0.487           |
| 1992               | 113                    | 187                    | -0.041                   | 0.942                     | 0.288           | 0.942  | 0.170           |
| 1993               | 96                     | 176                    | -0.020                   | 0.686                     | 0.682           | 0.686  | 0.389           |
| 1994               | 108                    | 179                    | 0.036                    | 1.096                     | 0.146           | 0.996  | 0.138           |
| 1995               | 125                    | 185                    | 0.090                    | 1.766                     | 0.003           | 0.351  | 0.782           |
| 1996               | 106                    | 160                    | 0.124                    | 1.780                     | 0.002           | 0.424  | 0.698           |
| 1997               | 112                    | 163                    | 0.077                    | 1.430                     | 0.024           | 0.690  | 0.385           |
| 1998               | 114                    | 147                    | 0.014                    | 0.735                     | 0.598           | 0.109  | 0.977           |

Note: Productivity differences (between both groups of firms) are calculated using the median of the distributions.

**Table 3. Number of first process innovating firms (small and large) per year.**

| <b>Year</b>     | <b>Large firms</b> | <b>Small firms</b> |
|-----------------|--------------------|--------------------|
| 1992            | 50                 | 52                 |
| 1993            | 27                 | 60                 |
| 1994            | 20                 | 49                 |
| 1995            | 13                 | 39                 |
| 1996            | 11                 | 35                 |
| 1997            | 10                 | 34                 |
| 1998            | 9                  | 49                 |
| Total 1992-1998 | 140                | 318                |

Note: We do not report data for 1991 as we need to start the test from 1992 onwards to calculate  $t-1$  TFP.

**Table 4. Comparison of ex-ante TFP between first-time process innovators and non-process innovators.**

|  | Number of observations        |                | Productivity differences | Equality of distributions |                 | Difference favourable to first-time process innovators |                 |
|--|-------------------------------|----------------|--------------------------|---------------------------|-----------------|--|-----------------|
|  | First-time process innovators | Non-innovators |                          | Statistic                 | <i>p</i> -value | Statistic  | <i>p</i> -value |
| <b>Small firms</b>   |                               |                |                          |                           |                 |  |                 |
| Productivity in <i>t-1</i> for first-time process innovators | 318                           | 365            | 0.076                    | 2.073                     | 0.000           | -0.035   | 0.997           |
| Mean previous productivity for first-time process innovators | 318                           | 365            | 0.079                    | 2.353                     | 0.000           | -0.125   | 0.969           |
| <b>Large firms</b>   |                               |                |                          |                           |                 |  |                 |
| Productivity in <i>t-1</i> for first-time process innovators | 139                           | 38             | 0.069                    | 1.432                     | 0.021           | -0.156   | 0.952           |
| Mean previous productivity for first-time process innovators | 140                           | 38             | 0.074                    | 1.645                     | 0.005           | -0.236   | 0.894           |

Note: Productivity differences (between both groups of firms) are calculated using the median of the distributions.

**Table 5. Comparison of TFP growth between first-time process innovators and non-process innovators.**

|   | Number of observations        |                      | TFP growth differences | Equality of distributions |                 | Differences favourable to first-time process innovators |                 |
|---|-------------------------------|----------------------|------------------------|---------------------------|-----------------|---|-----------------|
|   | First time process innovators | Non-innovative firms |                        | Statistic                 | <i>p</i> -value | Statistic   | <i>p</i> -value |
| <b>Small firms</b>  |                               |                      |                        |                           |                 |   |                 |
| Productivity growth between <i>t-1</i> and <i>t</i> for first-time process innovators | 318                           | 339                  | 0.0198                 | 2.156                     | 0.000           | -0.697  | 0.379           |
| <b>Large firms</b>  |                               |                      |                        |                           |                 |   |                 |
| Productivity growth between <i>t-1</i> and <i>t</i> for first-time process innovators | 139                           | 38                   | 0.032                  | 1.679                     | 0.004           | -0.655  | 0.423           |

Note: Productivity growth differences (between both groups of firms) are calculated using the median of the distributions.

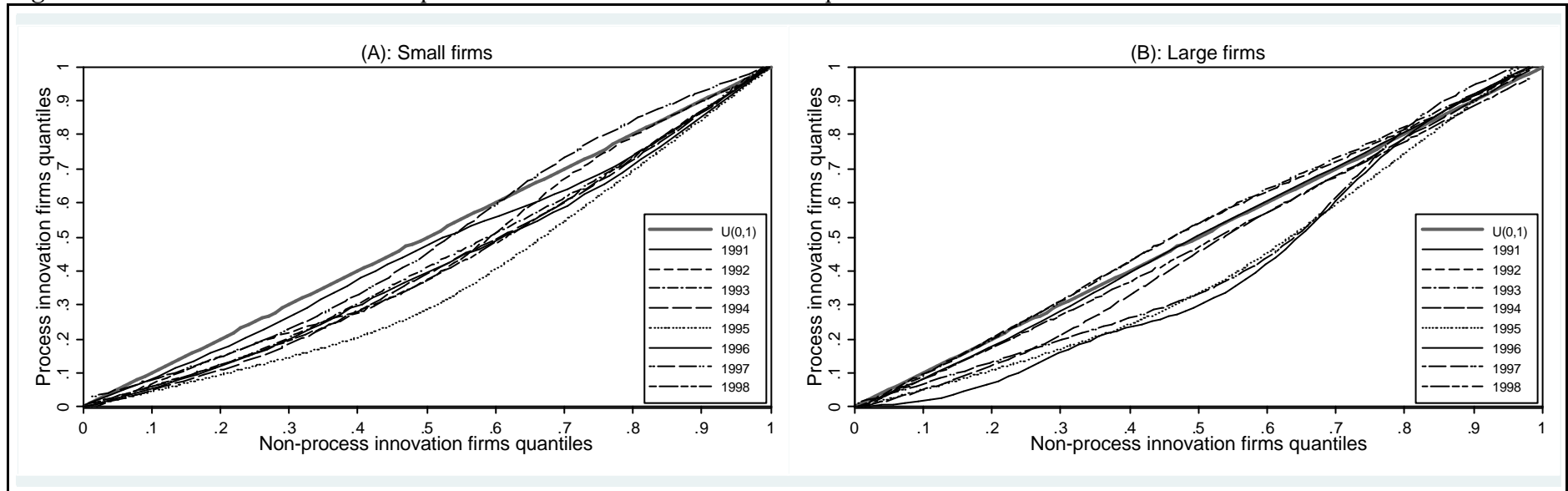
**Table 6. Comparison of TFP growth between first-time process innovators and non-process innovators.**

| Productivity growth of first time process innovators from $t+k$ to $t+k+1$ | Number of observations        |                      | Productivity growth differences | Equality of distributions |            | Differences favourable to first-time process innovators |            |
|--|-------------------------------|----------------------|---------------------------------|---------------------------|------------|---|------------|
|  | First-time process innovators | Non-innovative firms |                                 | Statistic                 | $p$ -value | Statistic   | $p$ -value |
| <b>Small firms</b>   |                               |                      |                                 |                           |            |   |            |
| From $t$ to $t+1$  | 103                           | 339                  | 0.019                           | 1.108                     | 0.139      | -0.689  | 0.387      |
| From $t+1$ to $t+2$  | 79                            | 339                  | 0.017                           | 1.077                     | 0.158      | -0.886  | 0.208      |
| From $t+2$ to $t+3$  | 61                            | 339                  | 0.000                           | 0.696                     | 0.660      | -0.696  | 0.380      |
| From $t+3$ to $t+4$  | 39                            | 339                  | 0.019                           | 0.991                     | 0.219      | -0.686  | 0.390      |
| <b>Large firms</b>   |                               |                      |                                 |                           |            |   |            |
| From $t$ to $t+1$  | 27                            | 38                   | 0.052                           | 1.770                     | 0.002      | -0.527  | 0.574      |
| From $t+1$ to $t+2$  | 22                            | 38                   | 0.029                           | 1.206                     | 0.068      | -0.241  | 0.890      |
| From $t+2$ to $t+3$  | 15                            | 38                   | 0.007                           | 1.013                     | 0.173      | -0.144  | 0.959      |
| From $t+3$ to $t+4$  | 12                            | 38                   | -0.007                          | 0.861                     | 0.332      | -0.861  | 0.227      |

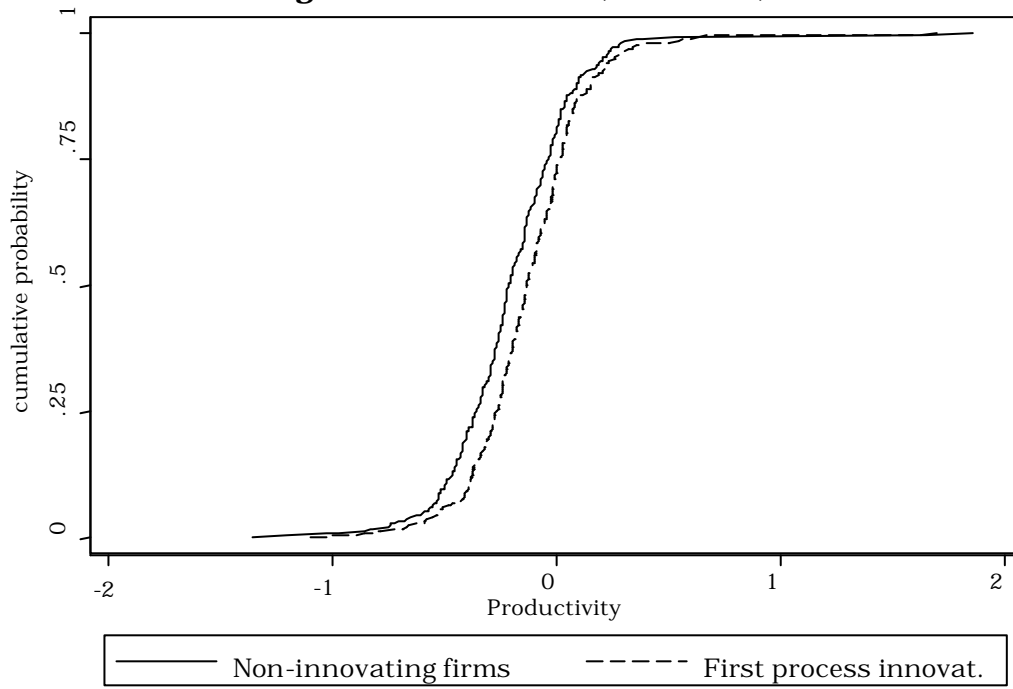
Note: Productivity growth differences (between both groups of firms) are calculated using the median of the distributions.

## Figures

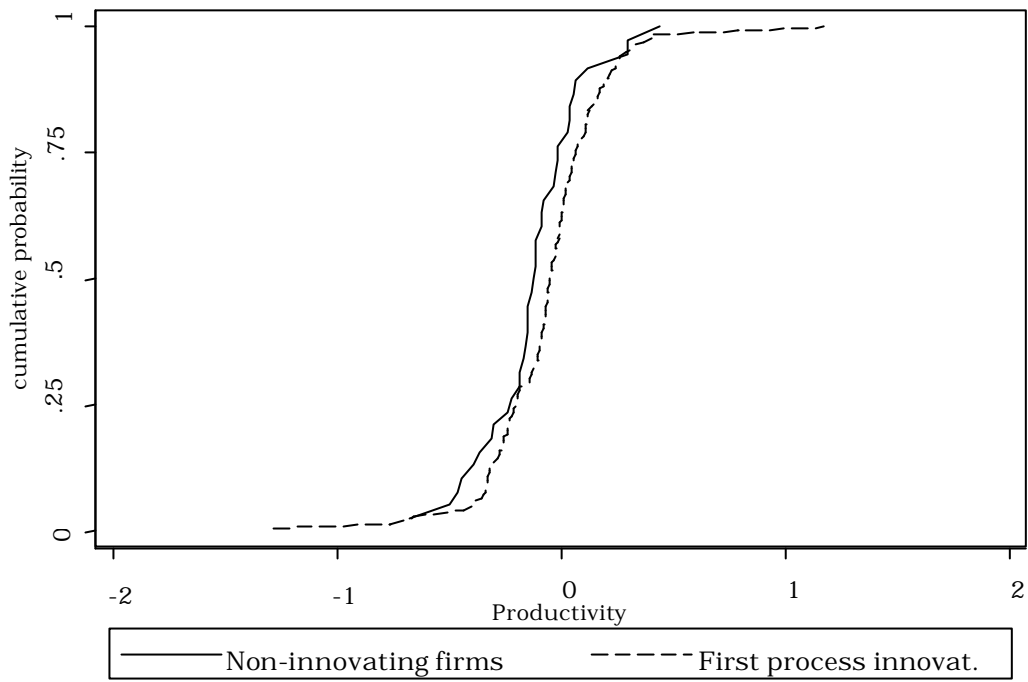
Figure 1: Relative distribution of process innovation firms to non-process innovation firms



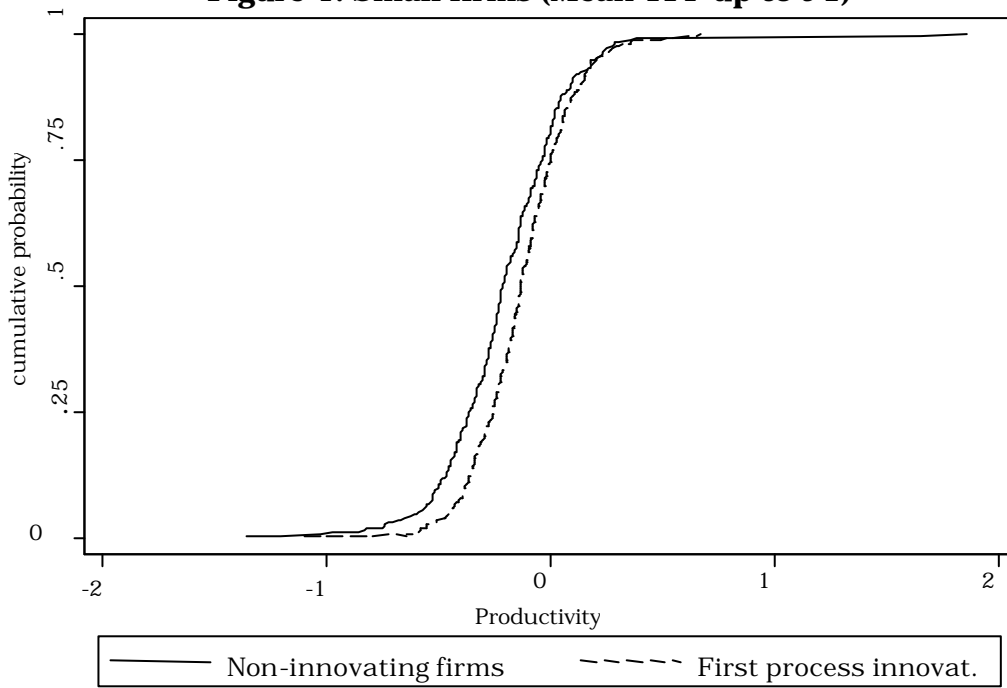
**Figure 2: Small firms (TFP in t-1)**



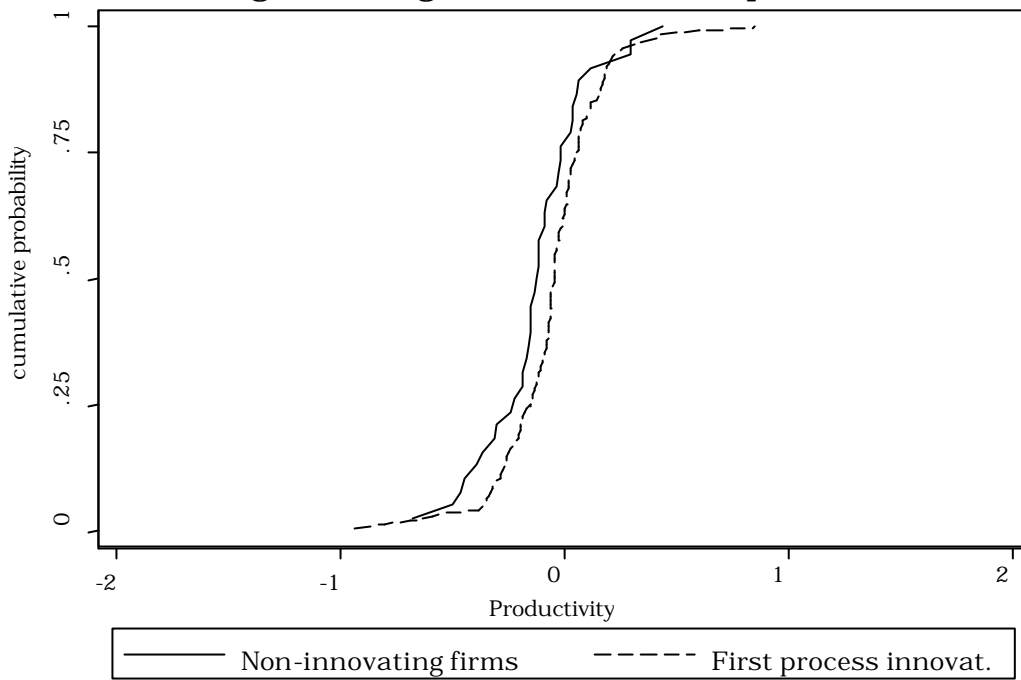
**Figure 3: Large firms (TFP in t-1)**



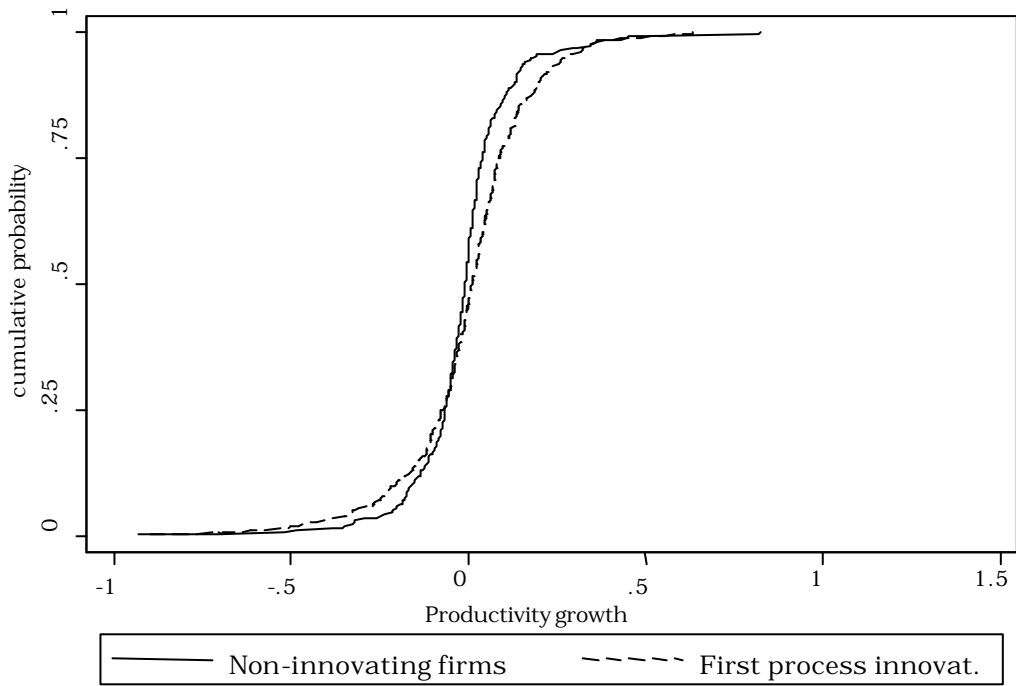
**Figure 4. Small firms (Mean TFP up to  $t-1$ )**



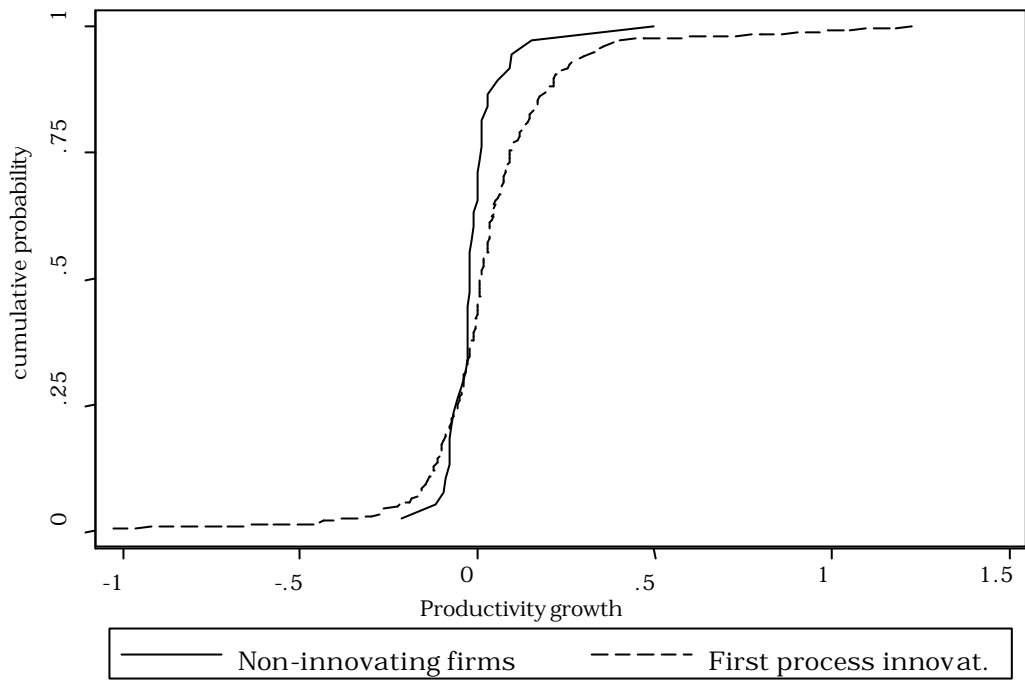
**Figure 5. Large firms (Mean TFP up to  $t-1$ )**



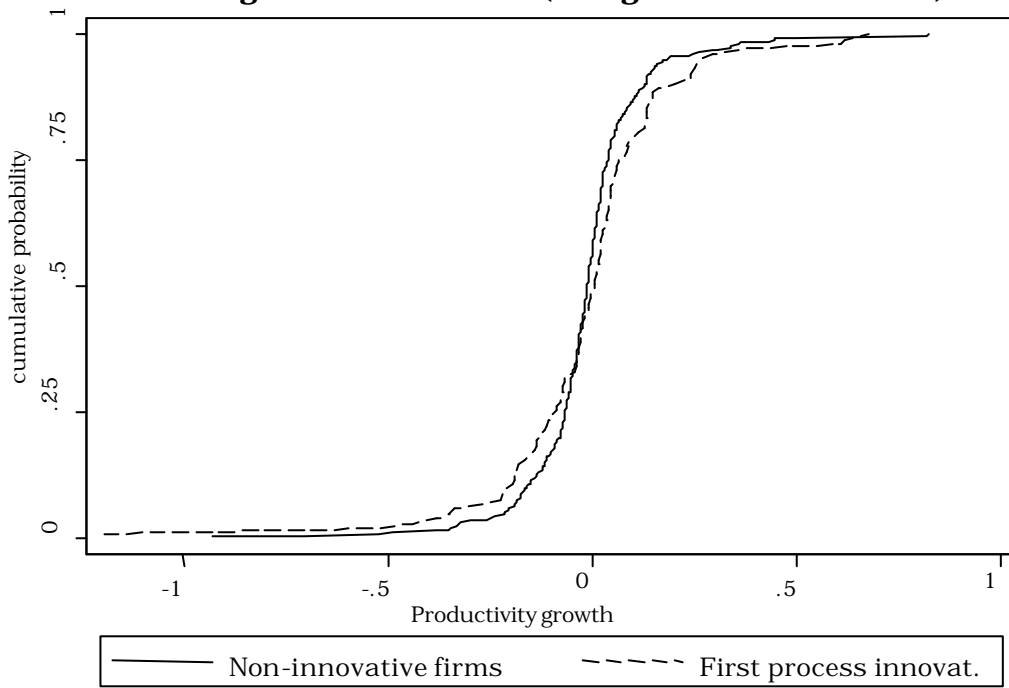
**Figure 6. Small firms (TFP growth from  $t-1$  to  $t$ )**



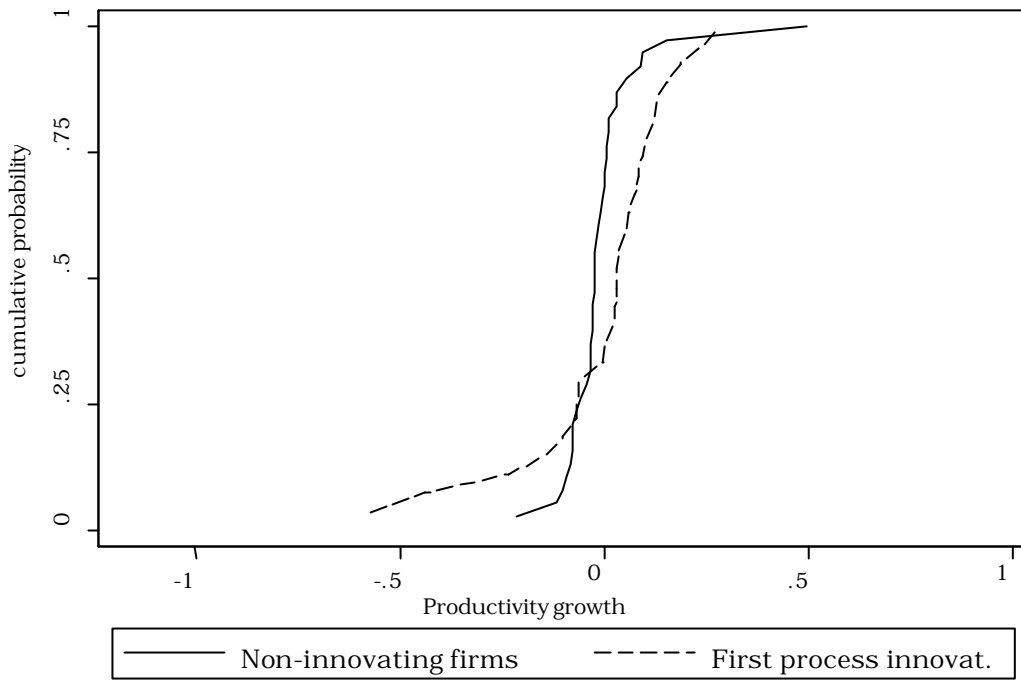
**Figure 7. Large firms (TFP growth from  $t-1$  to  $t$ )**



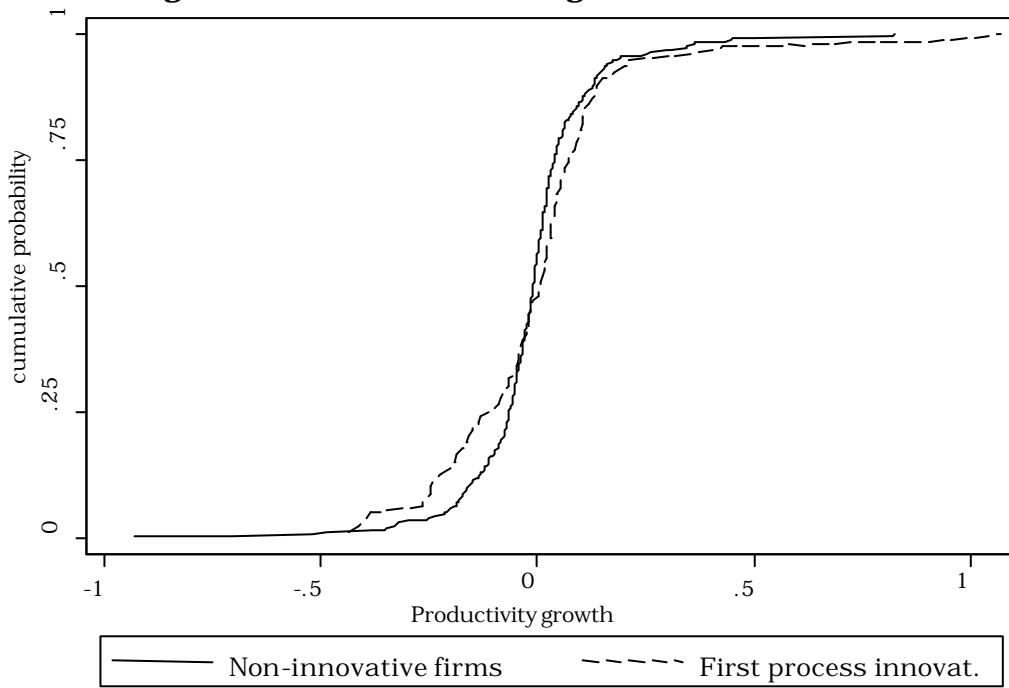
**Figure 8. Small firms (TFP growth from  $t$  to  $t+1$ )**



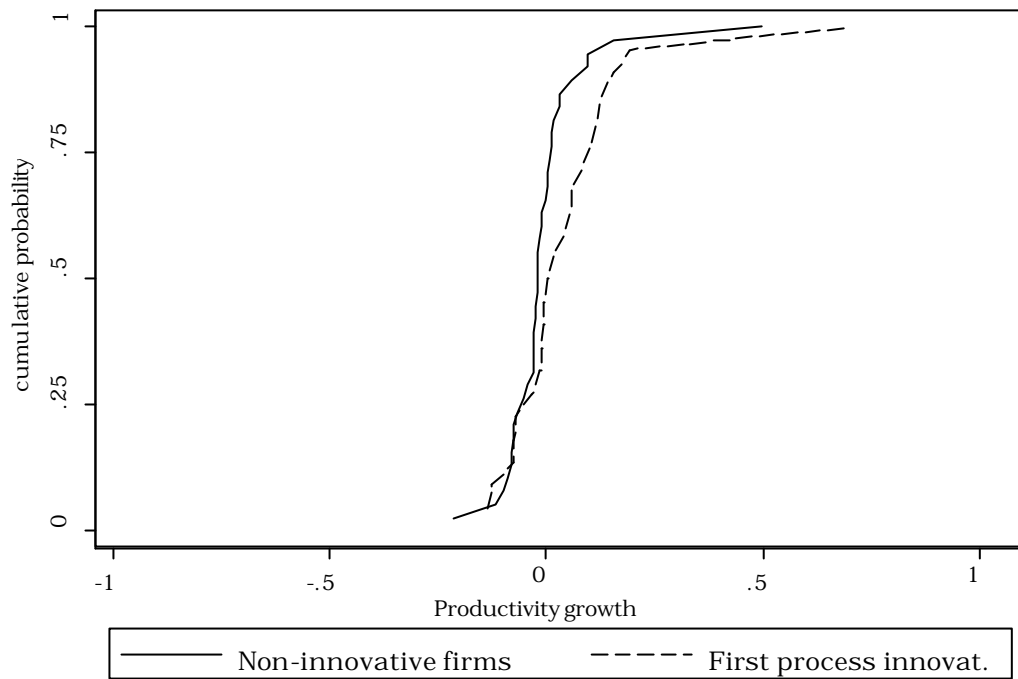
**Figure 9. Large firms (TFP growth from  $t$  to  $t+1$ )**



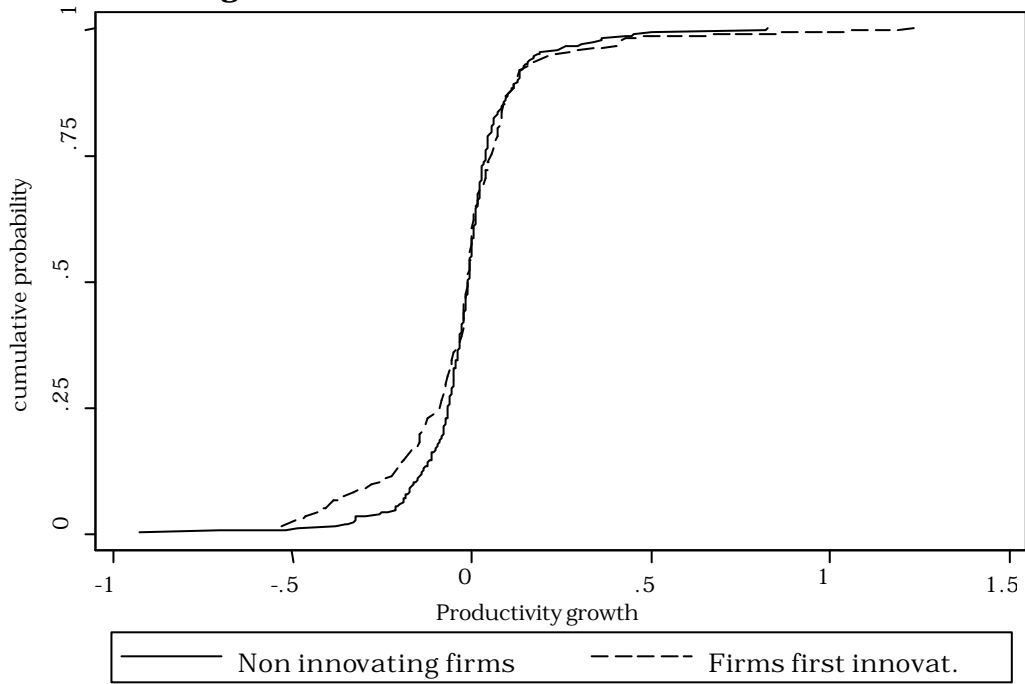
**Figure 10. Small firms (TFP growth from  $t+1$  to  $t+2$ )**



**Figure 11. Large firms (TFP growth form  $t+1$  to  $t+2$ )**



**Figure 12: Small firms (TFP from  $t+2$  to  $t+3$ )**



**Figure 13. Large firms (TFP growth from  $t+2$  to  $t+3$ )**

