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Outsourcing and Technological Change

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ABSTRACT

Outsourcing and Technological Change*

We present a dynamic model where the probability of outsourcing production is increasing in the firm's expectation of technological change. As the pace of innovations in production technologies increases, the less time the firm has to amortize the sunk costs associated with purchasing and adopting new technologies to produce in-house. Therefore, purchasing from market suppliers, who can afford to use the latest technology, becomes relatively cheaper. The predictions of the model are tested using a panel dataset on Spanish firms for the time period 1990 through 2002. In order to address potential endogeneity problems, we use an exogenous proxy for technological change, namely the number of patents granted by the U.S. patent office classified by technological class. We map the technological classes to the Spanish industrial sectors in which the patents are used and provide causal evidence of the impact of expected technological change on the likelihood and extent of production outsourcing. No prior study has been able to provide such causal evidence. Our results are robust to the inclusion of detailed characteristics of the firms as well as firm fixed effects.

JEL Classification: J21, L23, L24, O33

Keywords: outsourcing, technological change

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I. Introduction

Outsourcing, or the contracting out of activities to subcontractors outside the firm, has become widespread in many countries.[1] A number of explanations for the increase in outsourcing have been proposed and tested in the literature**.** Among them are that outsourcing is a response to unpredictable variations in demand (Abraham and Taylor, 1996), an opportunity to take advantage of the specialized knowledge of suppliers (Abraham and Taylor, 1996), and a method to save on labor costs (Abraham and Taylor, 1996; Autor, 2001; Diaz-Mora, 2005; and Girma and Gorg, 2004).[2]

Another important determinant of outsourcing is technology and this has been the subject of theoretical and empirical work. According to the transactions costs theory (Williamson 1975, 1985), if investments result in greater asset specificity, firms fearing expropriation of investments will reduce outsourcing. The property rights theory (Grossman and Hart, 1986) predicts that vertical integration between an upstream firm (the supplier) and a downstream firm (the final good producer) generates different costs and benefits to each of the parties. Therefore, the incentives to integrate or to outsource depend on which investments – the supplier's or the final good producer's – are relatively more important for the success of the joint relationship (Grossman and Hart, 1986; Gibbons, 2005; Hubbard, 2008).[3]

Some empirical studies have focused on testing these theories. In a study of U.K. manufacturing firms, Acemoglu et.al. (2010) found evidence consistent with the predictions of

[1] See Arndt and Kierzkowski (2001), Girma and Gorg (2004), Mol (2005), Magnani (2006) and Abramovsky and Griffith (2006).

[2] Other researchers (Ono (2007) and Holl (2008)) have studied the effect of agglomeration economies on outsourcing. For empirical studies of the impacts of outsourcing on wages and productivity, see Feenstra and Hanson (1999), Amiti and Wei (2006), Gorg, Hanley and Strobl (2007), Gorg and Hanley (2007), and Lopez (2002).

[3] Grossman and Helpman (2003, 2005) and Antras (2005a, 2005b) use the insights of the property rights theory to study important issues in international trade such as the decision to obtain intermediate inputs by engaging in foreign direct investment or contracting with arm's-length overseas suppliers.

the property rights theory, namely that technology intensity in the producing industry is associated with more vertical integration while technology intensity in the supplying industry is associated with less integration, where technology intensity is measured by R&D intensity. Lileeva and Van Biesebroeck (2008) also found evidence consistent with the predictions of the property rights model, using data on Canadian manufacturing firms. Mol (2005), however, found that in the Dutch manufacturing sector, R&D-intensive industries were able to solve the non-contractibility problem by using partnership relations with outside suppliers to reduce the likelihood of specific investments being appropriated.[4] Other studies that have examined the relationship between technology and outsourcing, without relying on the transactions cost or property rights theories, are Magnani (2006) who found evidence that technological diffusion driven by R&D spillovers was in part responsible for the growth of outsourced services in the U.S. and Abramovsky and Griffith (2006) who found that UK firms that were intensive in information and communication technologies were more likely to purchase services in the market.

In this paper we provide an alternative perspective on the relationship between technology and outsourcing. Unlike previous studies which have focused on the nature or intensity of technology, we focus on expectations of technology change. We present a dynamic model that analyzes how firms' expectations with regards to technological change influence the decision to outsource production, an issue ignored in the literature.[5] Our model abstracts from other considerations such as transactions costs or asset specificity. The model shows that outsourcing becomes more beneficial to the firm when technology is changing rapidly. A firm

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[4] Baker and Hubbard (2003) consider how information technology in the trucking industry impacts contracting possibilities and vertical integration. Baccara (2007) uses a general equilibrium model to study how information leakages could affect a firm's outsourcing decision as well as its investments in R&D.

[5] Lewis and Sappington (1991) present a model in which technological progress acts to reduce the cost asymmetries between suppliers and end users. In their model, technological progress reduces the suppliers' cost advantage, thereby making outsourcing less likely. Unlike Lewis and Sappington, our model does not consider the nature of technology but focuses instead on the rate of change of the technology.

can buy the latest technology and produce intermediate inputs in-house. Firms incur a sunk cost when adopting new technologies. Outsourcing, on the other hand, enables the firm to purchase inputs from supplying firms using the latest production technology while avoiding the sunk costs of the new technology. As the pace of innovations in production technology increases, the less time the firm has to amortize the sunk costs associated with purchasing the new technologies. This makes producing in-house with the latest technologies relatively more expensive than outsourcing. The model therefore provides an explanation for the recent increases in outsourcing that have taken place in an environment of increased expectations for technological change.

We test the predictions of the model using a panel dataset of Spanish firms for the time period 1990 through 2002. This dataset is superior to those used in previous studies of the determinants of outsourcing in several dimensions.[6] First, unlike many studies that used industry level data, we use a large sample of firms. Second, we have panel data that allow us to observe changes within firms over a long time period. Third, in addition to detailed information on outsourcing, the dataset provides rich information related to technological activities, such as the use of computers, investment in R&D, registration of patents, and product innovation.

While information on the firm's technological activities is likely to be correlated with the firm's expectations of technological change, these variables cannot be treated as purely exogenous. To address this endogeneity problem, we use the number of patents granted by the U.S. patent office classified by technological class and map the technological classes to the Spanish industries in which the patents are used.[7] The empirical results support the main prediction of the theoretical model, namely, that all other things equal, outsourcing increases with the probability of technological change. Our use of the patent variable enables us to conclude that this relationship is causal; no prior study has been able to provide causal evidence of the

[6] Holl (2008) used this dataset to study the effect of agglomeration economies on outsourcing and Lopez (2002) used it to study the impact of outsourcing on wages.
[7] Patents are commonly classified by the industry in which they originated, while our analysis calls for a classification by industry of use. In Section III we describe how we constructed such a measure.

impact of technological change on outsourcing. We also show that our results are robust to the inclusion of a measure of relationship-specific investments and furthermore that the patents variable remains significant when the analysis is restricted to industries with little relationship-specific investments. Importantly, this shows that our results cannot be explained by the transactions cost or property rights theories. Finally, our finding regarding the relationship between patents and outsourcing is robust to the inclusion of firm-level fixed effects, unlike the findings for many of the non-technology variables that prior researchers have studied.

Part II describes a simple dynamic model of the relationship between outsourcing and expected technological change. The complete model is given in the Appendix. Part III discusses the data and empirical specifications used to test the predictions of the model. Results are presented in Part IV. Part V concludes.

II. The Decision to Outsource Production

In this section we present a simple model that shows how the decision to outsource production is related to the probability of technological change. The complete model is presented in the Appendix**.** The model is motivated with the following example.

Suppose that the production of a final good requires an input that is composed of advanced capital equipment and labor. This input can either be produced in-house by the final good firm or it can be purchased in the market from an external supplier. The latter option amounts to outsourcing the production process. Installing the capital equipment and training the workforce to use the equipment involve expenses that are sunk to the firm. Suppose that technological change occurs in the sector supplying capital goods to this firm. For example, new IT-enhanced capital equipment becomes available for use in manufacturing.[8] The firm will need

[8] For example, in many manufacturing industries, computer numerically controlled (CNC) machines replaced numerically controlled machines which had previously replaced manual machines. See Bartel, Ichniowski and Shaw (2007) for a discussion of the impact of these new technologies on productivity in the valve-making industry.

to decide between making this capital investment or outsourcing the production of the final good to a firm that uses the new equipment. The relative costs of in-house production will increase if the frequency of technological change is increasing because the length of time over which a given fixed investment will benefit the firm becomes too short to justify incurring the sunk costs associated with the investment, making outsourcing the cheaper alternative.[9] The model we present below captures the essence of this example.

A firm produces a profit-maximizing amount q of a final good using a single input x. The model focuses on determining how to procure a given level of input x. There are two ways of obtaining x. One way is to produce x in-house, while the other way is to buy x in the market, which we refer to as "outsourcing production" . We implicitly assume that there are firms (the suppliers) willing to produce and supply x, i.e., there is an active market for x but we do not model the supply side here. The final good producer takes the price of x as given.

For simplicity we assume constant returns to scale in production. This allows us, after a normalization, to set $x = q$ which is desirable for the empirical work since q is observed. This assumption also ensures that the firm does not split x between in-house production and outsourcing. The firm will either produce all of x in-house or will outsource all of it.[10] Let $y_t = 1$ indicate that the firm decides to outsource x in period t, while $y_t = 0$ indicates in-house production of x.

[9] The firm could also attempt to lower its sunk costs by outsourcing the training of its workforce. For example, the firm may need to hire an instructor to train a single operator of the advanced equipment, but the same instructor could probably train more than one person simultaneously without incurring additional costs. The combination of a sunk cost and indivisibility (of the instructor) is precisely the feature being exploited by temporary employment agencies (Autor, 2001): they use the same instructor to train *several* workers in basic computer skills and offer them to firms at an attractive price because they can spread the sunk cost over a larger output (computer-skilled workers). Our model and empirical work does not consider outsourcing of training but rather focuses on the outsourcing of production.

[10] In reality, however, firms usually outsource part of their production, so that we should interpret x as one of the multiple input components of the final output.

In order to produce x in-house the firm uses another input which we call "machines" , each of which produces θ_t units of x. The productivity parameter θ evolves over time in a discrete fashion. That is, with probability λ, θ can jump to $\theta + \delta$ in the next period,

$$\theta_{t+1} = \begin{cases} \theta_t + \delta \text{ with probability } \lambda \\ \\ \theta_t \text{ with probability } 1 - \lambda \end{cases}$$

where $\delta > 0$.

Our goal is to show how the decision to outsource depends on λ, the probability of technological change. Note that technological change occurs in the sector producing the machines used in the production of x. Thus, we view technological change as embodied in machines.

The revenues obtained from selling the final good do not depend on the way in which x was procured. Thus, the decision to produce x in-house or to buy it in the market (outsource it) depends on which alternative is cheaper. At the beginning of each period, the state of technology is realized and the firm compares the costs of in-house production (C^0) to the costs of outsourcing (C^1).

Adopting a new technology involves the payment of $s \geq 0$ dollars to use it. The sunk cost s is associated with installing and using the machines of a given productivity for the first time. s is incurred only once and includes training costs. For simplicity, this sunk cost does not depend on the firm's previous experience with in-house production. Thus, there are no dynamic gains associated with in-house production.

When a new technology appears in the market a firm that decides to produce in-house can, in principle, always " skip" the new, upgraded machines. That is, the firm has the option to continue using the previous (old) technology if it has bought it in the past, or it could even buy the old technology in the market if it did not do so previously. It is not always profitable to adopt the latest technology. This adoption decision depends on whether using the upgraded technology is less costly than using the old technology. This is determined by the size of the sunk cost relative to the savings of using the latest technology. However, to simplify the analysis and because this adoption decision is not the focus of the paper, we will assume that upgrading always dominates keeping the old technology (and, as shown in the Appendix, we make the necessary assumptions that guarantee this is the optimal decision). Thus, if a firm decides to produce in-house it will always do so using the *latest* technology.

The cost of in-house production C^0 is therefore the cost of production using the *latest* technology available. A-fortiori, this assumption logically implies that suppliers of x in the market should always be producing with the latest technology because they spread the sunk cost of upgrading over a larger quantity of output. Thus, outsourcing involves buying x from suppliers using the latest technology.

The cost of in-house production C^0 depends on whether technology changed from last period and on the firm's outsourcing decision last period, y_{t-1}. If technology changed, the firm will pay the sunk cost s and other costs of production to produce q units of x. If there was no change in technology the firm does not need to pay s again if it already produced in-house last period $(y_{t-1} = 0)$ but, if it did outsource last period $(y_{t-1} = 1)$, it will have to pay s to produce in-house with the latest technology (the one existing last period). Thus, $C^0(\theta_t, \theta_{t-1}, y_{t-1}, s, q)$.

The cost of outsourcing C^1 depends on the market price of x which can vary with technology but it does not depend on y_{t-1}. The price of x, as well as the prices of the machines, may depend on the state of technology θ, as shown in the Appendix, but to simplify the notation here we do not condition on prices explicitly. Thus, $C^1(\theta_t, \theta_{t-1}, q)$.[11]

At the beginning of each period t, the firm observes the evolution of technology up to t, i.e., $(\theta_t, \theta_{t-1}, \theta_{t-2}, \ldots)$ and its past actions ($y_{t-1}, y_{t-2}, \ldots$), as well as the sunk cost s and the level of output q it wants to produce. The firm makes its (discrete) outsourcing decision in order to maximize the expected discounted value of its profits. Note that the Markovian nature of technology implies that only θ_t affects the future evolution of technology. However, because the costs of procuring x depend on whether θ_t is a new technology and on whether it was previously used or not (y_{t-1}), the firm bases its outsourcing decision at t also on θ_{t-1} and y_{t-1}.

Let $V(\theta_t, \theta_{t-1}, y_{t-1}, s, q)$ be the expected discounted value of the firm's stream of profits given $(\theta_t, \theta_{t-1}, y_{t-1}, s, q)$. V is defined by,

$$V(\theta_t, \theta_{t-1}, y_{t-1}, s, q) = Max\left\{V^0(\theta_t, \theta_{t-1}, y_{t-1}, s, q), V^1(\theta_t, \theta_{t-1}, y_{t-1}, s, q)\right\} \tag{1}$$

where V^0 is the expected discounted value if the firm decides to produce in-house during t, i.e., $y_t = 0$, and V^1 is defined similarly when the firm decides to outsource, i.e., $y_t = 1$.

The firm decides to outsource if, and only if,

$$y_t = 1 \Leftrightarrow V^1(\theta_t, \theta_{t-1}, y_{t-1}, s, q) - V^0(\theta_t, \theta_{t-1}, y_{t-1}, s, q) \geq 0 \tag{2}$$

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[11] In the formal model we also add other factors that affect the cost of outsourcing that are known to the firm but unobserved to the econometrician. These factors reflect adjustment costs due to loss of control over the input design, i.e., the additional cost of using a standardized input. This additional cost is absent when x is produced in-house because the firm can perfectly tailor the input to its specific needs.

In the Appendix we solve for $V^1 - V^0$ which completely determines the firm's outsourcing decision in period t as a function of $(\theta_t, \theta_{t-1}, y_{t-1}, s, q)$. This implies that there is a *threshold value* for the sunk cost s such that firms with s below the threshold produce in-house while those with sunk costs above the threshold outsource in period t.

This threshold value depends on the state variables as well as on the parameters of the model. We are interested in how the threshold value changes with λ. In the Appendix we show that the threshold value decreases with λ (for any value of the state) and therefore firms facing higher expectations of technological change in their inputs -- a higher λ -- are more likely to outsource, all other things equal.[12] Thus, when λ increases and new production technologies are more likely to appear in the future, firms will be more reluctant to buy the current machines today and produce in-house because these technologies will soon be obsolete. Upgrading the technology -- which is the optimal thing to do -- involves incurring a sunk cost di novo. The higher is λ, the more frequently the new machines arrive and the less time the firm has to amortize the sunk costs. Instead, the firm can use outsourcing to obtain x from supplying firms using the latest technology and avoid the sunk costs. All other things equal, an increase in λ decreases the cost of outsourcing relative to that of in-house production making the firm more likely to outsource. This is the main prediction of the model that we take to the data.

III. Data and Empirical Specification

We use data for 1990-2002 from the Encuesta sobre Estrategias Empresariales (ESEE, or Survey on Business Strategies), a survey of 3,195 Spanish manufacturing firms conducted by the Fundacion SEPI with the support of the Ministry of Industry, Tourism and Trade. The survey has

[12] In addition, larger firms and firms facing higher adjustment costs from outsourcing also have higher probabilities of producing in-house.

been conducted annually since 1990 and is an unbalanced panel. In 1990, all firms with more than 200 employees were asked to participate in the survey (with a response rate of 70 percent). Firms with 10-200 employees were chosen according to a random sampling scheme. In subsequent years, as firms dropped from the survey, new firms were incorporated into the sample using the same sampling criteria as in the base year. There are approximately 1800 firms in each year of the survey.

The survey includes annual information on firms' production outsourcing decisions, defined as a contractual relationship in which the firm commissions a third party to produce products, parts, or components made to the firm's specifications.[13] We use this information to create two indicators of production outsourcing: a dummy for whether or not the firm engaged in outsourcing, and the value of outsourcing divided by total costs. Total costs are defined as the sum of: (1) labor costs, (2) the cost of external services (R&D, advertising, public relations and other) and (3) purchases of goods for sale in the same condition in which they were acquired, raw materials and other consumables, and work carried out by subcontractors. The items in (3) are reported in the survey as an aggregate figure.

Table 1 shows the percentage of firms that reported outsourcing at least some part of production during the 1990 – 2002 time period and the mean value of the outsourced production as a percentage of total cost. On average, 43% of firms reported that they outsourced production during this time period. The outsourcing percentage rose from 35% in 1990 to 42% in 2002, with even higher values in some of the intervening years. There is significant variation in the likelihood of outsourcing across industries ranging from a low of 7.7% for "man-made fibers" to a high of 77.5% for "agricultural and forestry machinery". The average value of the outsourced production as a percentage of total costs is 5.4 percent during this time period; for firms that did outsource production, the mean value of outsourced production as a percentage of total costs is 13

[13] Production outsourcing does not include purchases of non-customized products, parts or components.

percent, with a low of 1.8 percent (industrial process control equipment) and a high of 23.7 percent (agricultural and forestry machinery).

The model in the Appendix derives the decision to outsource, y_{it} , as a function of expected technological change, λ, size of the firm (output or sales), lagged outsourcing and input prices. Under the assumption that input prices are common to all firms in an industry, these will be captured by industry dummies (ID). The main implication of the model presented in Part II is that, all other things equal, the probability of outsourcing increases with the exogenous probability of technological change, λ, which is given to the firm and represents the probability of technological change in the production process. The model also predicts that the probability of outsourcing decreases with sales, q_t.

As a first approximation to the model, we estimate equation (3):

$$y_{it} = \beta \lambda_{it} + \alpha q_{it} + \sum_j \delta_j ID_{ij} + u_{it} \tag{3}$$

where the dependent variable is either of the two measures of outsourcing. Later, we add dynamics to this equation.

In order to test the main prediction of the model, we need a proxy for λ, the firm's expectations with regard to technological change in its production process. The Spanish dataset includes a number of variables which might be reasonable proxies for λ. The firm's investment in R&D or its patent registrations can be good proxies to the extent that R&D (or patenting) is used to adapt exogenous changes in the production technology to the specific requirements of the firm. The notion of R&D serving this adaptive role has been tested by Cohen and Leventhal (1989). Another suitable proxy could be whether the firm engages in product innovation since this may be facilitated by exogenous changes in production technologies. Summary statistics for R&D

intensity, patent registrations, and product innovation are shown in Appendix Table A-1. While these variables are likely to be correlated with the firms' expectations of technological change in its production process, they could be endogenous if unobserved factors drive these decisions as well as the decision to outsource. For example, firms that are unobservably more "innovative" or "creative" may be engaging in more R&D, registering patents, engaging in product innovations and outsourcing production.

We can partially address this concern by exploiting the panel nature of our data which allows us to control for time-invariant unobserved factors that affect both the decision to engage in R&D (and therefore increase λ) and to outsource. Inclusion of fixed effects also enables us to control for other factors that affect the cost of outsourcing such as adjustment costs due to loss of control over input design. But adding fixed effects does not address all sources of endogeneity of the proposed proxies for λ. Causality could also go in the other direction. For example, the decision to outsource could induce the firm to shift from secrecy to patenting in order to protect an innovation.[14]

In order to address this concern, we use a proxy for λ which, by construction, is exogenous to the firm. This proxy is the number of patents granted yearly by the U.S. Patent Office that are linked to the industry in which the patents are used. These data are obtained from the NBER Patent Citations Data File described in Hall, Jaffe and Trajtenberg (2001). The industrial sector to which a patent is assigned is usually not identical to the sector using the patented invention. Hence it is necessary to convert data on the number of patents originating in an industry into the number of patents used by an industry. We are able to do this conversion using an algorithm kindly provided by Daniel Johnson as described in Johnson (2002). This algorithm takes the data on patents originating in the U.S. in each year and creates a count of the number of patents used by each of 38 manufacturing sectors (based on the ISIC classification).

[14] For this reason, technological change might deter firms from outsourcing the production of a product or component for which competitors could more easily copy or steal an innovation (Williamson, 1985).

We then matched these 38 sectors to the 44 manufacturing sectors used in the ESEE. Table 2 shows the contemporaneous patent counts for 1990 through 2002 assigned to each of the Spanish manufacturing sectors. The patent counts for the later years are significantly lower than those in earlier years because of the time lag between submission of a patent application and the actual granting of the patent. Note that seven industries (energy machinery, non-specific-purpose machinery, agricultural and forestry machinery, machine-tools, special purpose machinery, weapons and ammunition, and domestic appliances) were assigned the same patent counts because the ISIC classification groups these industries together.

For the regressions, we calculated, for each year, the average number of patents used in the sector over the previous three years and assigned this value to each Spanish firm based on its industrial sector. The three period lag is used instead of the contemporaneous value of patents for two reasons. First, year to year variations in patents are volatile and using information over a three year period smooths the data.[15] Second, given the time lag between patent application and patent granting, using the average of patent counts over the prior three years, rather than the current year plus the prior two years, enables us to include 2002 in our analysis. The U.S. patents variable is clearly exogenous to the outsourcing decisions of the Spanish firm and enables us to estimate the causal impact of expected technological change on outsourcing.

Our model predicts that larger firms will be less likely to outsource and we therefore include the firm's sales in the equation. We also control for a set of variables that have been the subject of previous research on the determinants of outsourcing. Since firms may use outsourcing as a way of economizing on labor costs (see Abraham and Taylor, 1996), we include the firm's average labor cost defined as total annual spending (wages and benefits) on employees divided by total employment. Outsourcing may also be used to smooth the workload of the core workforce during peaks of demand (Abraham and Taylor, 1996; Holl, 2008). Hence, we add a measure of capacity utilization defined as the average percentage of the standard production capacity used

[15]We tried shorter and longer time horizons and our results were unchanged.

during the year. Another factor that can increase the propensity to outsource is the volatility in demand for the product (Abraham and Taylor, 1996; Holl, 2008). We proxy volatility using two dummy variables that indicate whether the company's main market expanded or declined during the year. It has also been argued that very young firms may be less likely to outsource because they have not had sufficient time to learn about the quality and reliability of potential subcontractors (Holl, 2008) and we therefore include the age of the firm. Whether the firm primarily produces standardized products or custom made products could also affect the propensity to outsource production if custom made products involve more frequent changes in the production process. We add a dummy variable that equals one if the firm indicated that it produces standardized products that are, in most cases, the same for all buyers. Finally, we control for the firm's export propensity, the value of exports divided by sales (Girma and Gorg, 2004; Diaz-Mora, 2005; and Holl, 2008).[16] Summary statistics on all of these variables are shown in Appendix Table A-1.

IV. Results

We use two dependent variables, an indicator of whether the firm is engaged in outsourcing production and the value of the firm's outsourced production as a percentage of total costs. Regressions using the first dependent variable are estimated with fixed effect Logit while random effect Tobit is used for the second dependent variable since 60 percent of the observations are zeroes. Table 3 uses the proxies for expected technological change that come directly from the Spanish data (whether the firm engaged in R&D, registered patents or introduced new products) while Tables 4 and 5 use the exogenous measure of expected technological change based on the U.S. patent filings.

[16] The firm's location could also serve as a proxy for the ease with which outsourcing can be done (see Ono, 2007). Our data do not provide this information, but a firm's location is likely to be time-invariant and its potential effect on outsourcing is captured by the firm fixed effect in our regressions.

A. Expected Technological Change

Table 3 shows the coefficients on the technological change proxies from fixed effect Logit regressions and random effect Tobit regressions. Marginal effects from the Logit regressions are evaluated at the mean. Marginal effects from the Tobit regressions are shown for the probability of outsourcing a positive amount, the expected value of the dependent variable conditional on outsourcing a positive amount, and the unconditional expected value of the dependent variable. The coefficients in Table 3 are from regressions that include industry dummies, sales, and additional control variables; the coefficients on the additional variables are shown in Table 7, where column (2) uses the exact specification from column (2b) in Table 3.[17] The proxies for technological change (R&D, product innovation, and patent registration) are all positive and significant in both the fixed effect Logits and the random effect Tobits. According to the Logit estimates, firms that engage in R&D are 7 percent more likely to outsource and firms that engage in product innovation or register patents are 5 percent more likely to outsource. We note that since these variables are all proxies for expected technological change and we do not know the true relationship between the proxies and the actual value for expected technological change, it is difficult to interpret the magnitudes of the coefficients. Hence, we prefer to conclude simply that there is a positive and significant relationship between outsourcing and these proxies. However, as explained in Part III, we cannot infer causation from these results because the firm's decision to engage in R&D, create new products and/or register patents is endogenous.

Table 4 presents the results of fixed effect Logit and random effect Tobit regressions that use the exogenous proxy for expected technological change based on patent counts in the U.S. The complete regressions are shown in Appendix Table A-2. The patent variable is positive and significant in all columns of Table 4. This is strong evidence of a causal relationship between

[17] In column (1) of Table 7 we report the estimated coefficients of a logit regression without firm fixed effects but with industry dummies.

expected technological change and the decision to outsource production as well as the extent of outsourcing. As explained above, we cannot interpret the magnitudes of the coefficients on patents in Table 4.

In Table 5, we show the coefficients on the patent variable from random effects Logit and Tobit regressions that use the specification generated from the model presented in the Appendix; complete regression results are in Appendix Table A-3. Adding dynamics to the model, i.e. including lagged outsourcing as a regressor, requires that we address the initial conditions problem. We follow Wooldridge (2005) in specifying a homoskedastic normal density for the unobserved firm effect conditional on the exogenous variables and initial outsourcing. We express the unobserved effect as a linear combination of the time averages of the exogenous variables, initial outsourcing and a normal error term which is then integrated out from the likelihood function. The results in Table 5 are virtually identical to those in Table 4; the causal impact of U.S. patents on the outsourcing decisions of Spanish firms remains even when we add dynamics to the model.

B. Alternative Explanations

The prior literature on vertical integration and outsourcing has focused on the role played by relationship-specific investments in a context where at least some part of the contract is non-verifiable ex post and hence non-contractible ex ante (Gibbons, 2005; Hubbard, 2008; Acemoglu et.al., 2010). Our model on the other hand, focuses on expectations of technology change and implicitly assumes full contractibility. It is possible, and perhaps likely, that both approaches - - expectations about technological change and the existence of incomplete markets - - play a role in explaining outsourcing. Since we have not controlled for the specificity of investment, we are concerned that our estimates of the effect of technological expectations may be reflecting the effect of incomplete markets on outsourcing.

In order to control for the effect of incomplete markets on outsourcing, we turn to the proxy for relationship-specific investments created by Nunn (2007). Nunn used 1997 data to calculate the proportion of each industry's intermediate inputs that are sold on an organized exchange or reference priced in a trade publication. He defines "differentiated inputs" as inputs that are neither sold on an organized exchange nor reference priced in a trade publication. As in Nunn (2007), we use the measure of differentiated inputs as a proxy for the extent to which an industry is subject to industry-specific investments. We matched Nunn's data to the industrial sectors in the ESEE and re-estimated the regressions in Table 4 adding the differentiated inputs variable.[18] The results, shown in Panel A of Table 6, demonstrate that the patent variable remains positive and significant. Note also that the effect of the differentiated inputs variable is positive and significant which is consistent with the property rights theory in the case of the input supplier's investments dominating the relationship.[19] The positive coefficient on the differentiated inputs variable rules out a role for the transactions cost theory because this theory predicts that vertical integration is more likely in the presence of relationship-specific investments.

In Panel B, we delete firms that are in industries that have a large share of relationship-specific inputs, defined as having a value above the median for the Nunn variable. In this way we restrict the analysis to firms in industries which have a small share of relationship-specific inputs. Since the property rights theory of outsourcing is based on the role of relationship-specific inputs, by focusing on industries where relationship-specific inputs are less important, the property rights theory of outsourcing would have less relevance for these industries. In Panel B, we find that the patent variable remains positive and significant for these industries. In other words, our finding regarding a positive relationship between U.S. patent filings and production outsourcing by

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[18] We are unable to estimate fixed effects Logit regressions because the Nunn variables are only available for one year.

[19] The Nunn variable is positively but marginally significantly correlated with the patent measure we use for 1997 (i.e. the mean over 1994-1996) as well as with the mean number of patents over the 1990-2002 time period (.268 and .243, with significance levels of 9 percent and 13 percent, respectively.)

Spanish firms holds for firms that are in industries where relationship-specific inputs are not important. For these firms, the property rights theory would not be relevant, while our model of expected technological change still applies. Hence, we conclude that our findings on the effects of technological expectations on outsourcing do not reflect the effect of incomplete markets.

C. Other Determinants of Outsourcing

Table 7 presents the coefficients on the non-technology variables described in Section III. Column (2) corresponds to the specification in column (2b) of Table 3. Column (1) shows the results without firm fixed effects. In columns (3) through (6), the analysis is restricted to 1990, 1994, 1998 and 2002 because these are the only years in which data on some of the non-technology variables were collected. Columns (3) and (4) use identical specifications, except that Column (4) includes firm fixed effects. Finally, Columns (5) and (6) report the specifications from Columns (1) and (2) but restrict the sample to the four years in which data for all of the non-technology variables are available.

Unlike the proxies for expected technological change, the coefficients on the non-technology variables in the model are not robust to the inclusion of fixed effects. When firm fixed effects are not included in the regressions, some of the non-technology variables are significant, supporting results from the prior literature. As shown in previous research (Abraham and Taylor, 1996; Holl (2008) the volatility of demand for the product as proxied by market expansion, is positively correlated with the probability of outsourcing. High average labor costs are also associated with outsourcing in columns (3) and (5), consistent with previous work (Abraham and Taylor, 1996). But we find no effect of sales which is at odds with the prediction of our model.[20] The firm's export propensity is positively correlated with outsourcing. But, importantly, none of these results remain significant when we add fixed effects. We conclude that findings from

[20] Holl (2008) suggested that large firms may be more likely to outsource because they have greater capacity to establish and manage subcontracting relationships. If this is true, it would offset the negative relationship that our model predicts.

previous studies that rely on cross-sectional analyses may not be robust.

V. Conclusions

Previous research on the relationship between technology and outsourcing has focused on the roles played by asset specificity, technological diffusion, and information and communications technology. In this paper we study the outsourcing of production and we propose an alternative perspective on the relationship between technological change and outsourcing. We present a dynamic model that shows that outsourcing becomes more beneficial to the firm when technology is changing rapidly. The intuition behind the model is that as the pace of innovations in production technology increases, the less time the firm has to amortize the sunk costs associated with purchasing the new technologies. This makes producing in-house with the latest technologies relatively more expensive than outsourcing. The model therefore provides an explanation for the recent increase in outsourcing that has taken place in an environment of increased expectations for technological change.

We test the predictions of the model using a panel dataset on Spanish firms for the time period 1990 through 2002. This dataset is superior to those used in previous studies of outsourcing because it enables us to observe changes within firms over a long time period. Our econometric analysis controls for unobservable fixed characteristics of the firms and, most importantly, uses an exogenous measure of expected technological change, i.e. the number of patents granted by the U.S. patents office in the Spanish firm’s industrial sector. The empirical results support the main prediction of the model, namely, that all other things equal, outsourcing of production increases with expected technological change. Our use of the patent variable enables us to conclude that this relationship is causal; no prior study has been able to provide causal evidence of the impact of technological change on production outsourcing. We also show that our results are robust to the inclusion of a measure of relationship-specific investments and furthermore that the patents variable remains significant when the analysis is restricted to industries with little relationship-specific investments. This shows that our results cannot be explained by the transactions costs or property rights theories of the firm. Furthermore, while the existing literature has found evidence that non-technology variables play a role in the decision to outsource, we find no such evidence here when accounting for firms' fixed effects.

References

Abraham, K. and S. Taylor (1996). "Firms' Use of Outside Contractors: Theory and Evidence." *Journal of Labor Economics* 14: 394-424.

Abramovsky, L. and R. Griffith (2006). "Outsourcing and Offshoring of Business Services: How Important is ICT?" *Journal of the European Economic Association* 4:594-601.

Acemoglu, D., P. Aghion, R. Griffith, and F. Ziliboti (2010), "Vertical Integration and Technology: Theory and Evidence," *Journal of the European Economic Association*.

Amiti, M. and S.J. Wei (2006). "Service Offshoring and Productivity: Evidence from the United States", NBER Working Paper 11926.

Antras, Pol (2005a). "Property Rights and the International Organization of Production," *AEA Papers and Proceedings*, 95(2): 25-32.

Antras, Pol (2005b). "Incomplete Contracts and the Product Cycle." *American Economic Review*, 95(4): 1054-73.

Arndt, S.W. and H. Kierzkowski (2001). *Fragmentation: New Production Patterns in the World Economy* (New York: Oxford University Press).

Autor, D. (2001). "Why Do Temporary Help Firms Provide Free General Skills Training?" *Quarterly Journal of Economics*, 118 (4): 1409-1448.

Baccara, M. (2007). "Outsourcing, Information Leakage and Consulting Firms," *The Rand Journal of Economics*, 38:269-289.

Baker, G. and Hubbard, T. (2003): "Make versus Buy in Trucking: Asset Ownership, Job Design and Information," *American Economic Review*, June: 551-572.

Bartel, A., Ichniowski, C. and K. Shaw (2007). "How Does Information Technology Affect Productivity? Plant-Level Comparisons of Product Innovation, Process Improvement and Worker Skills," *Quarterly Journal of Economics*, 122(4): 1721-1758.

Benkard, C. Lanier (2000). "Learning and Forgetting: The Dynamics of Aircraft Production," *American Economic Review*, September: 1034-54.

Cohen W.M. and D.A. Levinthal (1989). "Innovation and Learning: The Two Faces of R&D", *Economic Journal*, September: 569-596.

Diaz-Mora, C. (2005): "Determinants of Outsourcing Production: A Dynamic Panel Data Approach for Manufacturing Industries." Foundation for Applied Economics Studies working paper.

Feenstra, R.C. and G.H. Hanson (1999). "The Impact of Outsourcing and High-Technology Capital on Wages: Estimates for the United States, 1979-1990", *Quarterly Journal of Economics* 114:907-941.

Girma and Gorg (2004). "Outsourcing, Foreign Ownership, and Productivity: Evidence from UK Establishment-level Data," *Review of International Economics* 12:817-832.

Gibbons, Robert (2005). “Four Formal(izable) Theories of the Firm?” *Journal of Economic Behavior & Organization* 58:200-245.

Gordon, Robert J. (1990). *The Measurement of Durable Goods Prices,* Chicago: University of Chicago Press

Gorg, H., A. Hanley and E. Strobl (2007). “Productivity Effects of International Outsourcing: Evidence from Plant-level Data”, *Canadian Journal of Economics*.

Gorg, H. and A. Hanley (2007). “International Services Outsourcing and Innovation: An Empirical Investigation”. working paper.

Grossman, S. and O. Hart (1986). “The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration”, *Journal of Political Economy* 94(4): 691-719.

Grossman, S. and E. Helpman (2003). “Outsourcing versus FDI in Industry Equilibrium,” *Journal of the European Economic Association*, 1(2-3): 317-327.

Grossman, S. and E. Helpman (2005). “Outsourcing in a Global Economy.” *Review of Economic Studies*, 72(1): 135-169.

Hall, B. H., A. B. Jaffe, and M. Tratjenberg (2001). "The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools." NBER Working Paper 8498.

Holl, A. (2008). “Production Subcontracting and Location,” *Regional Science and Urban Economics* 38(3): 299-309.

Hubbard, T. (2008). “Viewpoint: Empirical research on firms’ boundaries”, *Canadian Journal of Economics* 41:341-359.

Johnson, Daniel K.N. (2002), “The OECD Technology Concordance (OTC): Patents by Industry of Manufacture and Sector of Use”.

Lewis, T.R. and D.E.M. Sappington (1991). “Technological Change and the Boundaries of the Firm,” *American Economic Review* 81: 887-900.

Lileeva, A. and J. Van Biesebroeck (2008). “Outsourcing When Investments are Specific and Complementary.” NBER Working Paper No. 14477, November.

Lopez, A. (2002). “Subcontratacion de servicios y produccion: evidencia par alas empresas manufactureras espanolas,” *Econmia Indsutrial*, 348:127-140.

Magnani, E (2006). “Technological Diffusion, the Diffusion of Skill and the Growth of Outsourcing in US Manufacturing,” *Economics of Innovation and New Technology*

Mol, M. (2005). “Does Being R&D-Intensive Still Discourage Outsourcing? Evidence from Dutch Manufacturing,” *Research Policy* 34:571-582.

Nunn, N. (2007). “Relationship-Specificity, Incomplete Contracts, and the Pattern of Trade,” *The Quarterly Journal of Economics*, May, 569-600.

Ono, Y. (2007). “Outsourcing Business Services and the Scope of Local Markets,” *Regional Science and Urban Economics* 37: 220-238.

Williamson, O. (1975). *Markets and Hierarchies: Analysis and Antitrust Implications,* New

York: The Free Press.

Williamson, O. (1985). *The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting,* New York: The Free Press.

Wooldridge, J. (2002). *Econometric Analysis of Cross Section and Panel Data*, Cambridge: MIT Press.

Wooldridge, J. (2005). "Simple Solutions to the Initial Conditions Problem for Dynamic, Nonlinear Panel Data Models with Unobserved Heterogeneity," *Journal of Applied Econometrics* 20: 39-54.

Appendix:
A Model of Production Outsourcing

In this Appendix we derive the model sketched in Section II.

Let p_{kt} be the cost of renting each machine if there is no technological change in period t, i.e., $\theta_t = \theta_{t-1}$, and p_{kt}^T be the cost when there is technological change, i.e., $\theta_t = \theta_{t-1} + \delta$. It is conceivable that the price of machines depends on improvements to the machines. We assume that the quality-adjusted price of machines decreases when technology improves, i.e.,

$$\frac{p_{kt}^T}{\theta_{t-1} + \delta} \le \frac{p_{kt}}{\theta_{t-1}} \qquad \text{(A-1)}$$

as often claimed (Gordon, 1990).

Given that each machine produces θ_t units of x, the total cost of producing q units of x in-house with the *latest* technology θ_t is therefore,

$$C_t^0 = C(y_t = 0) = \left[p_{kt}^T \frac{q}{\theta_t} + s_t \right] I\left(\theta_t = \theta_{t-1} + \delta\right) + \left[p_{kt} \frac{q}{\theta_t} + \alpha s_t y_{t-1} \right] I\left(\theta_t = \theta_{t-1}\right) \qquad \text{(A-2)}$$

where $I(\cdot)$ is an indicator function taking the value of one when the statement within the parentheses is true and zero otherwise.

Equation (2) embeds several assumptions. First, when a new technology appears and is adopted by the firm, it has to pay $s_t \ge 0$ dollars to use it. The sunk cost s_t is associated with installing and using the machines of a given productivity for the first time. s_t is incurred only once and includes training costs. For simplicity, this sunk cost does not depend on the firm's previous experience with in-house production. Thus, there are not dynamic gains associated with in-house production.

Second, when there is no technological change and the firm produced in-house last period $(y_{t-1} = 0)$ then, as stated, the firm does not incur the sunk cost again. If, however, the firm did *not* produce in-house last period $(y_{t-1} = 1)$ then it pays a fraction $0 < \alpha \le 1$ of the sunk cost. It is less costly to adopt a technology that was introduced in previous periods. Note, however, that we do not allow α to depend on the time span between the current period and the period at which the latest technology appeared in the market. That is, the firm pays αs even if the current technology θ_t has remained unchanged for many periods. Note also that the firm pays αs for the old technology as long as it outsourced during $t-1$. That is, even if the firm used the (old) technology in periods $t-2$ or earlier, but skipped using it in period $t-1$, it has to pay a fraction α of the sunk cost. This assumption reflects "organizational forgetting" which occurs when the firm does not use a technology for a period of time (Benkard, 2000).

When a new technology appears the firm can in principle ignore it and continue using the previous (old) technology. The upgrading or adoption decision depends on whether using the upgraded technology is less costly than using the old technology. This is determined by the size of the sunk cost relative to the savings of using the latest technology, $\left(\frac{p_{kt}}{\theta_{t-1}} - \frac{p_{kt}^T}{\theta_{t-1} + \delta} \right) q$. To simplify the analysis, and because this adoption decision is not the focus of the paper, we assume that upgrading always dominates keeping the old technology. This assumption requires not too large sunk cost or, alternatively, large enough cost savings. Therefore, for any t, we restrict s_t to

$$0 \le s_t \le \bar{s} < \left(\frac{p_{kt}}{\theta_{t-1}} - \frac{p_{kt}^T}{\theta_{t-1} + \delta} \right) q_0 \tag{A-3}$$

where q_0 is the minimal amount of output that is profitable to produce.

Assumption (A-3) implies that if the firm decides to produce in-house it will always do so using the *latest* technology. Equation (A-2) therefore refers to the costs of producing x in-house using the latest technology available. A-fortiori, this assumption logically implies that suppliers of x in the market should always be producing with the latest technology because they spread the sunk cost of upgrading over a larger quantity of output.

The other alternative to procuring x is by purchasing it in the market. The cost of outsourcing q units of x is

$$C_t^1 = C(y_t = 1) = p_t^T q I\left(\theta_t = \theta_{t-1} + \delta\right) + p_t q I\left(\theta_t = \theta_{t-1}\right) + v \tag{A-4}$$

where p_t^T and p_t are, respectively, the unit price of x in the presence and absence of technological change at t and v represents other factors affecting the outsourcing decision.

Presumably, the suppliers of x are also facing more productive machines and may therefore lower their prices depending on the competitive environment in the market for x. Thus, we want to allow for the possibility of firms lowering their prices when their inputs are more productive. For the empirical part it is important to model other factors affecting the decision to outsource that are known to the firm but unobserved to the econometrician. $v \ge 0$ reflects adjustment costs due to loss of control over the input design, i.e., the additional cost of using a standardized input. This additional cost is absent when x is produced in-house because the firm can perfectly tailor the input to its specific needs.

The revenues R_t obtained from selling the final good do not depend on the way in which x was procured. Thus, profits are given by

$$\begin{aligned} \pi_t^0 &= \pi^0(\theta_t, \theta_{t-1}, y_{t-1}) = R_t - C_t^0 \\ \pi_t^1 &= \pi^1(\theta_t, \theta_{t-1}, y_{t-1}) = R_t - C_t^1 \end{aligned} \tag{A-5}$$

Note that profits from in-house production are determined by technology and, because of the presence of sunk costs, by past outsourcing decisions, while profits from outsourcing are not. Because revenues are equal, differences in profits reflect differences in the costs of procuring x,

$$\pi_t^1 - \pi_t^0 = \left[s_t - (z_t^T + v) \right] I\left(\theta_t = \theta_{t-1} + \delta\right) + \left[\alpha s_t y_{t-1} - (z_t + v) \right] I\left(\theta_t = \theta_{t-1}\right) \tag{A-6}$$

where

$$z_t^T = \left(p_t^T - \frac{p_{kt}^T}{\theta_{t-1} + \delta} \right) q$$

$$z_t = \left(p_t - \frac{p_{kt}}{\theta_{t-1}} \right) q$$

z_t^T and z_t are, respectively, the difference in variable cost between outsourcing and producing in-house when there is and there is no technological change. Note that if the suppliers of x in the market use the same technology as the final good producers then z_t and z_t^T are the operating profits of these suppliers (gross of fixed costs) and these should therefore be non-negative. The price paid to an outside supplier may be lower than its in-house marginal cost when the production of x is subject to increasing returns or learning effects which confer a cost advantage to suppliers producing (relatively) large amounts of x to serve a large market. In this case, all firms will outsource. The interesting case is therefore when $z_t \geq 0$ and $z_t^T \geq 0$ and we maintain this assumption. To simplify the analysis, we also assume that suppliers' margins are constant over time so that, for any q,

$$z_t^T = z^T, \quad z_t = z \quad \text{for all } t. \tag{A-7}$$

At the beginning of period t, the firm observes the evolution of technology up to t, i.e., $(\theta_t, \theta_{t-1}, \theta_{t-2}, \ldots)$ and its past actions. The firm makes its (discrete) outsourcing decision in order to maximize the expected discounted value of its profits. Note that the Markovian nature of technology implies that only θ_t affects the future evolution of technology. However, because costs of in-house production depend on whether θ_t is a new technology and on whether it was previously used or not (y_{t-1}), the firm also needs to know θ_{t-1} and y_{t-1} in order to make a decision on y_t (but nothing else). Thus, the firm decides upon y_t based on its observation of $(\theta_t, \theta_{t-1}, y_{t-1})$ and its expectation of future profits.

Let $V(\theta_t, \theta_{t-1}, y_{t-1})$ be the expected discounted value of the firm's stream of profits given $(\theta_t, \theta_{t-1}, y_{t-1})$. V is defined by,

$$V(\theta_t, \theta_{t-1}, y_{t-1}) = Max\left\{V^0(\theta_t, \theta_{t-1}, y_{t-1}), V^1(\theta_t, \theta_{t-1}, y_{t-1})\right\} \tag{A-8}$$

where V^0 is the expected discounted value if the firm decides to produce in-house during t, i.e., $y_t = 0$, and V^1 is defined similarly when the firm decides to outsource, i.e., $y_t = 1$.

The firm decides to outsource if, and only if,

$$y_t = 1 \Leftrightarrow V^1(\theta_t, \theta_{t-1}, y_{t-1}) - V^0(\theta_t, \theta_{t-1}, y_{t-1}) \geq 0$$

The value from in-house production (outsourcing) equals current profits $\pi^0(\pi^1)$ plus the discounted expected value next period given in-house production (outsourcing) today,

$$\begin{aligned} V^0(\theta_t, \theta_{t-1}, y_{t-1}) &= \pi^0(\theta_t, \theta_{t-1}, y_{t-1}) + \beta E_t V(\theta_{t+1}, \theta_t, 0) \\ V^1(\theta_t, \theta_{t-1}, y_{t-1}) &= \pi^1(\theta_t, \theta_{t-1}, y_{t-1}) + \beta E_t V(\theta_{t+1}, \theta_t, 1) \end{aligned} \tag{A-9}$$

where $0 < \beta < 1$ is the discount factor and E_t represents the expectation of a function of θ_{t+1} conditional on θ_t and alternative values of y_t.

In order to evaluate the last terms in (A-9) we note that because technology in period $t+1$ remains at θ_t with probability $(1-\lambda)$ or jumps to $\theta_t+\delta$ with probability λ we have,

$$E_t V(\theta_{t+1},\theta_t,0) = (1-\lambda)V(\theta_t,\theta_t,0)+\lambda V(\theta_t+\delta,\theta_t,0)$$
$$E_t V(\theta_{t+1},\theta_t,1) = (1-\lambda)V(\theta_t,\theta_t,1)+\lambda V(\theta_t+\delta,\theta_t,1)$$

Given our simplifying assumptions, when a new technology appears the costs of both alternatives -- outsourcing and in-house production -- do not depend on y_{t-1}. Thus, when there is technological change, the past history of in-house production does not matter. This implies, $V(\theta_t+\delta,\theta_t,0)=V(\theta_t+\delta,\theta_t,1)$.

Given the model's assumptions

$$V(\theta_t,\theta_t,1)-V(\theta_t,\theta_t,0) = -\alpha\left[\underline{s}-\int_0^{\underline{s}} G(s)ds\right] \equiv -\alpha B(\underline{s}) \qquad \text{(A-10)}$$

where G is the distribution function of s and

$$B(\underline{s}) = \underline{s}-\int_0^{\underline{s}} G(s)ds \geq 0$$
$$\underline{s} = \frac{z+v}{\left(1-\beta(1-\lambda)\right)\alpha}$$

P roof. Using (A-8) when $\theta_{t+1}=\theta_t=\theta$ and $y_t=1$ as well as (A-9) we get

$$V(\theta,\theta,1) = V^0(\theta,\theta,1)+Max\left\{0,V^1(\theta,\theta,1)-V^0(\theta,\theta,1)\right\}$$

$$= V^0(\theta,\theta,1)+Max\left\{0,\pi^1(\theta,\theta,1)-\pi^0(\theta,\theta,1)+\beta(1-\lambda)\left[V(\theta,\theta,1)-V(\theta,\theta,0)\right]\right\}$$

Similarly, we have

$$V(\theta,\theta,0) = V^0(\theta,\theta,0)+Max\left\{0,\pi^1(\theta,\theta,0)-\pi^0(\theta,\theta,0)+\beta(1-\lambda)\left[V(\theta,\theta,1)-V(\theta,\theta,0)\right]\right\}$$

The difference in the firm's value between outsourcing and in-house production when $\theta_{t+1}=\theta_t=\theta$ is therefore

$$V(\theta,\theta,1)-V(\theta,\theta,0) = V^0(\theta,\theta,1)-V^0(\theta,\theta,0)$$
$$+Max\left\{0,\pi^1(\theta,\theta,1)-\pi^0(\theta,\theta,1)+\beta(1-\lambda)\left[V(\theta,\theta,1)-V(\theta,\theta,0)\right]\right\}$$
$$-Max\left\{0,\pi^1(\theta,\theta,0)-\pi^0(\theta,\theta,0)+\beta(1-\lambda)\left[V(\theta,\theta,1)-V(\theta,\theta,0)\right]\right\}$$

From (A-9) and (A-5) we have $V^0(\theta,\theta,1)-V^0(\theta,\theta,0)=\pi^0(\theta,\theta,1)-\pi^0(\theta,\theta,0)=-\alpha s_{t+1}$.

Let $V(\theta,\theta,1)-V(\theta,\theta,0)=D_{t+1}$ and $z=\left(p_{t+1}-\dfrac{p_{kt+1}}{\theta_t}\right)q$ (which is constant over time by assumption (7)). D_{t+1} must satisfy,

$$D_{t+1} = -\alpha s_{t+1}+Max\left\{0,\alpha s_{t+1}-z-v+\beta(1-\lambda)D_{t+1}\right\}-Max\left\{0,-z-v+\beta(1-\lambda)D_{t+1}\right\}$$

This implies $D_{t+1}\leq 0$. As explained above we assume that $z\geq 0$ and therefore $Max\left\{0,-z-v+\beta(1-\lambda)D_{t+1}\right\}=0.$ Thus,

$$D_{t+1} = -\alpha s_{t+1} + Max\{0, \alpha s_{t+1} - z - v + \beta(1-\lambda)D_{t+1}\}$$

For $0 \le s_{t+1} \le \frac{z+v}{\left(1-\beta(1-\lambda)\right)\alpha} \equiv \underline{s}$ we let D_{t+1} on the RHS be $-\alpha s_{t+1}$, and for $\underline{s} < s \le \bar{s}$ we let the RHS be equal to $-\frac{z+v}{1-\beta(1-\lambda)}$. We want to check that the RHS operator returns these values. It can be easily checked that

$$D_{t+1} = -\alpha s_{t+1} + Max\{0, \alpha s_{t+1} - z - v + \beta(1-\lambda)D_{t+1}\} = \begin{cases} -\alpha s_{t+1} & 0 \le s_{t+1} \le \underline{s} \\ -\frac{z+v}{1-\beta(1-\lambda)} = -\alpha \underline{s} & \underline{s} < s_{t+1} \le \bar{s} \end{cases}$$

If $\underline{s} > \bar{s}$ then $V(\theta_t, \theta_t, 1) - V(\theta_t, \theta_t, 0) = -\alpha s_{t+1}$ for any $s_{t+1} \le \bar{s}.$

Note that D_{t+1} depends on s_{t+1} and we denote $D_{t+1} = D(s_{t+1})$. We now average D_{t+1} over s_{t+1} using the distribution of sunk costs $G.$ Abusing the notation, we obtain

$$V(\theta,\theta,1) - V(\theta,\theta,0) = -\alpha\left[\int_0^{\underline{s}} sg(s)ds + \int_{\underline{s}}^{\bar{s}} \underline{s}g(s)\right]$$

$$= -\alpha\left[\underline{s} - \int_0^{\underline{s}} G(s)ds\right]$$

This proves equation (A-10).

Note that $\int_0^{\underline{s}} G(s)ds \le \underline{s}$ and therefore $V(\theta,\theta,1) - V(\theta,\theta,0) \le 0$ because, when there is no technological change, outsourcing at $t+1$ is more costly that producing in-house (there are no sunk costs since the firm is already using the latest technology at t) .

Using (A-6), (A-10) and the equality between $V(\theta_t + \delta, \theta_t, 0)$ and $V(\theta_t + \delta, \theta_t, 1),$ the gains from outsourcing $V^1(\theta_t, \theta_{t-1}, y_{t-1}) - V^0(\theta_t, \theta_{t-1}, y_{t-1})$ can be written as,

$$V^1 - V^0 = \begin{cases} s_t - z^T - v - \beta(1-\lambda)\alpha B(\underline{s}) & \theta_t = \theta_{t-1} + \delta \\ \alpha s_t y_{t-1} - z - v - \beta(1-\lambda)\alpha B(\underline{s}) & \theta_t = \theta_{t-1} \end{cases} \quad \text{(A-11)}$$

These equations completely determine the firm's outsourcing decision in period t as a function of the firm's sunk cost at t and $\left(\theta_t, \theta_{t-1}, y_{t-1}\right)$ and other factors (z, z^T, v). In every period, the firm draws a sunk cost from the distribution G and decides whether to outsource or not according to (A-11). It is important to have heterogeneity in s_t (or in v) . Otherwise, *all* firms of a given size q would be either outsourcing or producing in-house which is in general contrary to the facts.

The first row in (A-11) indicate that when there is technological change the decision to outsource does not depend on y_{t-1}. This is a result of our assumption on the lack of dynamic gains from previous in-house experience. Thus, the probability of outsourcing at t conditional on a technological jump is,

$$P(y_t = 1 | \theta_t = \theta_{t-1} + \delta, z^T, z, v) = P\left(s_t \geq z^T + v + \beta(1-\lambda)\alpha B(\underline{s})\right) \qquad \text{(A-12)}$$
$$= 1 - G\left(z^T + v + \beta(1-\lambda)\alpha B(\underline{s})\right)$$

It can be easily shown that

$$\frac{dB(\underline{s})}{d\underline{s}} = 1 - G(\underline{s}) \geq 0$$
$$\frac{\partial \underline{s}}{\partial \lambda} = -\frac{\underline{s}\beta}{\left(1-\beta(1-\lambda)\right)} \leq 0$$
$$\frac{\partial B(\underline{s})}{\partial \lambda} = -\frac{\left(1-G(\underline{s})\right)\underline{s}\beta}{1-\beta(1-\lambda)} \leq 0$$

where g is the density function of s.

When technological change occurs, the probability of outsourcing increases with λ and decreases with $z+v$. Thus, firms facing higher expectations of technological change in their inputs are more likely to outsource, while larger firms (larger q) and firms facing higher per unit cost of outsourcing are less likely to outsource.

Note that when there is no technological change, $\theta_t = \theta_{t-1}$, and the firm did not outsource in the previous period, $y_{t-1} = 0$, the gains from outsourcing are always non-positive. Because marginal cost of in-house production is lower than p_t and the firm already paid the sunk cost (since it was producing in-house last period with the latest technology which did not change) it will continue producing in-house in period t. That is,

$$P(y_t = 1 | y_{t-1} = 0, \theta_t = \theta_{t-1}, z^T, z, v) = 0 \qquad \text{(A-13)}$$

In other words, the model implies that in-house producers will *only* outsource when there is technological change.

When the firm outsourced in period $t-1$, and there is no technological change, it may decide to produce in-house in period t if the realized sunk cost s_t is low enough. Thus, the probability of outsourcing is less than one (even if the technology does not change). From (A-11) we can easily compute,

$$P(y_t = 1 | y_{t-1} = 1, \theta_t = \theta_{t-1}, z^T, z, v) = P(s_t \geq \frac{z+v}{\alpha} + \beta(1-\lambda)B(\underline{s})) \qquad \text{(A-14)}$$
$$= 1 - G\left(\frac{z+v}{\alpha} + \beta(1-\lambda)B(\underline{s})\right)$$

As in the previous case, the probability of outsourcing conditional on $\left(\theta_t, \theta_{t-1}, y_{t-1}\right)$ increases with λ and decreases with $z+v$.

Thus, when λ increases and new production technologies are more likely to appear in the future, firms will be more reluctant to buy the current machines today and produce in-house because these technologies will soon be obsolete. Upgrading the technology -- which is the optimal thing to do -- involves incurring a sunk cost di novo. The higher is λ, the more frequently the new machines arrive and the less time the firm has to amortize the sunk costs. Instead, the firm can use outsourcing to obtain x from supplying firms using the latest technology and avoid the sunk costs. All other things equal, an increase in λ decreases the cost of outsourcing relative to that of in-house production making the firm more likely to decide to outsource. The main prediction of the model that we take to the data is that the probability of outsourcing increases with λ.

Table 1
Value of Outsourcing by Field (1990-2002)

	Incidence of Outsourcing			Value of Outsourcing ÷ Total Costs	
	Mean	**Std Dev**	**N**	**All**	**If >0**
Field					
Food, beverages	0.210	0.407	3461	0.020	0.100
Tobacco products	0.580	0.497	69	0.034	0.068
Textile	0.433	0.496	1099	0.048	0.110
Wearing apparel	0.536	0.499	1394	0.102	0.190
Leather articles	0.391	0.488	744	0.064	0.163
Wood products	0.279	0.449	603	0.035	0.127
Paper	0.339	0.474	638	0.038	0.115
Publishing, printing	0.582	0.493	1136	0.095	0.165
Petroleum products, nuclear fuel	0.444	0.527	9	0.081	0.216
Basic chemical	0.252	0.435	326	0.017	0.069
Paints, varnishes	0.175	0.381	228	0.007	0.041
Pharmaceuticals	0.592	0.492	557	0.044	0.076
Soaps, detergents, toilet preparation	0.484	0.501	250	0.035	0.075
Other chemicals	0.400	0.492	125	0.019	0.048
Man-made fibers	0.077	0.277	13	0.001	0.013
Rubber and plastics products	0.477	0.500	1066	0.046	0.098
Non-metallic mineral products	0.266	0.442	1610	0.027	0.103
Basic metals	0.302	0.460	665	0.026	0.089
Fabricated metal products	0.477	0.500	1798	0.059	0.125
Energy machinery	0.479	0.501	213	0.048	0.105
Non-specific purpose machinery	0.715	0.452	281	0.100	0.144
Agricultural and forestry machinery	0.775	0.420	89	0.176	0.237
Machine-tools	0.712	0.455	104	0.118	0.169
Special purpose machinery	0.592	0.492	397	0.100	0.177
Weapons and ammunition	0.740	0.443	50	0.125	0.170
Domestic appliances	0.622	0.486	196	0.143	0.235
Office machinery and computers	0.421	0.497	76	0.035	0.085
Electric motors, generators, transformers	0.615	0.489	109	0.053	0.090
Electric distribution, control, wire	0.622	0.486	267	0.063	0.098
Accumulators, battery	0.646	0.481	79	0.140	0.220
Lighting equipment	0.547	0.499	179	0.071	0.135
Other electrical equipment	0.727	0.447	176	0.071	0.101
Electronic components	0.400	0.491	165	0.023	0.058
Signal transmission, telecommunication	0.770	0.422	122	0.084	0.114
TV & radio receivers, audiovisual electronics	0.570	0.498	86	0.100	0.182
Medical equipment	0.533	0.503	60	0.033	0.066
Measuring instruments	0.719	0.451	139	0.108	0.152
Industrial process control equipment	0.375	0.518	8	0.007	0.018
Optical instruments	0.690	0.467	58	0.120	0.176
Motor vehicles	0.539	0.499	951	0.072	0.140
Other transport equipment	0.647	0.479	467	0.108	0.171
Furniture	0.374	0.484	1077	0.050	0.135
Other manufacturing industries	0.530	0.500	560	0.052	0.100
Year					
1990	0.348	0.476	2045	0.047	0.138
1991	0.466	0.499	1879	0.049	0.116
1992	0.438	0.496	1797	0.054	0.127
1993	0.418	0.493	1698	0.052	0.130
1994	0.405	0.491	1683	0.049	0.122
1995	0.414	0.493	1519	0.051	0.125
1996	0.425	0.494	1539	0.055	0.132
1997	0.441	0.497	1741	0.059	0.135
1998	0.461	0.499	1608	0.061	0.132
1999	0.423	0.494	1594	0.060	0.144
2000	0.440	0.497	1719	0.057	0.130
2001	0.429	0.495	1580	0.056	0.133
2002	0.422	0.494	1567	0.054	0.128
All Firms	0.425	0.494	21700	0.054	0.130

Table 2
U.S. Patent Counts Assigned to Spanish Field of Use

	Year																
	1987	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**Total**
Field																	
Food, beverages	1,678	1,779	1,864	1,864	1,830	1,938	1,967	2,094	2,332	2,232	2,458	2,299	2,335	1,779	643	47	29,139
Tobacco products	172	183	180	178	173	161	145	179	201	206	214	216	196	126	37	2	2,569
Textile	825	950	966	967	897	957	951	1,064	1,161	1,149	1,245	1,166	1,087	781	323	15	14,504
Wearing apparel	337	362	395	417	399	355	409	417	473	488	538	536	529	421	216	7	6,299
Leather articles	262	276	275	234	235	214	293	293	328	330	383	349	337	249	98	1	4,157
Wood products	346	377	381	396	374	363	387	406	443	444	490	484	468	344	109	5	5,817
Paper	918	1,049	1,072	1,113	1,121	1,145	1,176	1,295	1,436	1,383	1,609	1,440	1,356	985	335	13	17,446
Publishing, printing	1,143	1,297	1,408	1,474	1,480	1,665	1,671	1,910	2,107	2,277	2,479	2,375	2,154	1,695	528	19	25,682
Petroleum products, nuclear fuel					653	652	620	642	670	604	695	660	619	436	135	7	6,393
Basic chemical	2,863	3,194	3,438	3,525	3,430	3,445	3,349	3,387	4,112	3,426	3,863	3,440	3,431	2,573	922	49	48,447
Paints, varnishes	392	441	477	495	478	488	495	495	588	531	595	520	492	357	123	5	6,972
Pharmaceuticals	2,356	2,543	2,736	2,819	2,722	3,125	3,267	3,896	5,276	3,396	4,158	3,694	3,593	2,677	1,124	82	47,464
Soaps, detergents, toilet preparation	391	461	450	438	442	443	506	564	697	668	725	645	695	533	226	28	7,912
Other chemicals	959	1,051	1,105	1,152	1,143	1,159	1,140	1,187	1,385	1,211	1,362	1,260	1,234	945	353	22	16,668
Man-made fibers	257	284	307	286	282	268	278	298	343	332	369	327	331	236	91	2	4,291
Rubber and plastics products	2,710	3,164	3,316	3,308	3,324	3,304	3,400	3,561	4,096	3,832	4,268	3,833	3,590	2,496	729	24	48,955
Non-metallic mineral products	967	1,069	1,088	1,091	1,112	1,042	1,051	1,094	1,235	1,180	1,369	1,198	1,198	851	250	7	15,802
Basic metals	954	1,084	1,037	1,055	1,024	1,027	1,043	1,052	1,105	1,106	1,176	1,174	1,119	914	297	7	15,174
Fabricated metal products	1,834	1,996	2,096	2,107	2,095	2,103	2,178	2,279	2,531	2,543	2,883	2,760	2,709	2,103	655	24	32,896
Energy machinery	12,403	13,649	14,561	15,040	15,436	15,982	16,217	18,278	20,595	22,171	25,546	24,505	22,241	16,819	6,471	243	260,157
Non-specific purpose machinery	12,403	13,649	14,561	15,040	15,436	15,982	16,217	18,278	20,595	22,171	25,546	24,505	22,241	16,819	6,471	243	260,157
Agricultural and forestry machinery	12,403	13,649	14,561	15,040	15,436	15,982	16,217	18,278	20,595	22,171	25,546	24,505	22,241	16,819	6,471	243	260,157
Machine-tools	12,403	13,649	14,561	15,040	15,436	15,982	16,217	18,278	20,595	22,171	25,546	24,505	22,241	16,819	6,471	243	260,157
Special purpose machinery	12,403	13,649	14,561	15,040	15,436	15,982	16,217	18,278	20,595	22,171	25,546	24,505	22,241	16,819	6,471	243	260,157
Weapons and ammunition	12,403	13,649	14,561	15,040	15,436	15,982	16,217	18,278	20,595	22,171	25,546	24,505	22,241	16,819	6,471	243	260,157
Domestic appliances	12,403	13,649	14,561	15,040	15,436	15,982	16,217	18,278	20,595	22,171	25,546	24,505	22,241	16,819	6,471	243	260,157
Office machinery and computers	3,868	4,569	5,037	5,517	5,862	6,495	7,013	8,924	11,600	13,382	16,419	15,714	11,554	6,177	2,391	102	124,624
Electric motors, generators, transformers	261	299	326	323	338	335	331	364	407	424	493	474	476	364	124	5	5,344
Electric distribution, control, wire	261	299	326	323	338	335	331	364	407	424	493	474	476	364	124	5	5,344
Accumulators, battery	261	299	326	323	338	335	331	364	407	424	493	474	476	364	124	5	5,344
Lighting equipment	261	299	326	323	338	335	331	364	407	424	493	474	476	364	124	5	5,344
Other electrical equipment	261	299	326	323	338	335	331	364	407	424	493	474	476	364	124	5	5,344
Electronic components	1,662	2,005	2,221	2,409	2,721	2,887	2,919	3,555	4,311	4,681	5,766	5,847	5,789	4,435	1,968	99	53,275
Signal transmission, telecommunication	996	1,163	1,321	1,355	1,466	1,576	1,706	2,195	2,745	3,275	3,969	3,677	2,614	1,454	530	23	30,065
TV & radio receivers, audiovisual electronics	1,548	1,803	1,940	2,010	2,130	2,152	2,259	2,857	3,272	3,562	4,153	3,434	2,600	1,492	502	26	35,740
Measuring instruments	2,471	2,736	2,972	3,013	3,053	3,122	3,178	3,711	4,130	4,360	5,004	4,775	4,510	3,145	1,016	37	51,233
Optical instruments	138	164	180	182	177	171	179	207	236	251	288	266	274	215	72	6	3,006
Motor vehicles	4,734	5,074	5,396	5,632	5,342	5,288	5,485	5,806	6,545	6,903	7,633	7,502	7,491	6,727	2,427	83	88,068
Other transport equipment	1,150	1,219	1,323	1,328	1,322	1,268	1,321	1,340	1,482	1,518	1,719	1,809	1,679	1,420	561	21	20,480
Furniture	1,998	2,180	2,320	2,474	2,424	2,486	2,658	2,916	3,115	3,271	3,656	3,495	3,381	2,702	950	36	40,062
Total	126,055	139,511	148,858	153,734	157,453	162,848	166,218	187,390	214,155	225,858	260,773	248,800	225,432	167,821	63,528	2,525	2,650,959

Table 3
Technological Change and Outsourcing, 1990-2002[a]
Using Data from Spanish Survey as Proxy for Technological Change

A. Dependent Variable is Incidence of Outsourcing (Fixed Effect Logit Regressions)

	(1a) *Coeff*	*(1b)* *Mfx*	*(2a)* *Coeff*	*(2b)* *Mfx*
R&D Activities	0.4424***	0.0971***	0.3354***	0.0725***
	(0.0829)	(0.0187)	(0.0780)	(0.0166)
Product Innovation	0.2715***	0.0594***	0.2259***	0.0486***
	(0.0645	(0.0146)	(0.0619)	(0.0134)
Patent Registration	0.1982*	0.0430*	0.2187**	0.0463**
	(0.1065)	(0.0226)	(0.1028)	(0.0211)
Year Dummies	No	No	Yes	Yes
N	11062	11062	12267	12267

B. Dependent Variable is Value of Outsourcing/Total Costs (Random Effect Tobit Regressions)

	(3a)	*(3b)*	*(3c)*	*(3d)*	*(4a)*	*(4b)*	*(4c)*	*(4d)*
		Marginal Effects				*Marginal Effects*		
	Coeff	*p(0,1)*[b]	*E(y|y>0)*[c]	*E(y*)*[d]	*Coeff*	*p(0,1)*[b]	*E(y|y>0)*[c]	*E(y*)*[d]
R&D Activities	0.0312***	0.0582***	0.0101***	0.0132***	0.0316***	0.0590***	0.0102***	0.0134***
	(0.0040)	(0.0076)	(0.0013)	(0.0018)	(0.0041)	(0.0076)	(0.0013)	(0.0018)
Product Innovation	0.0160***	0.0297***	0.0052***	0.0067***	0.0145***	0.0270***	0.0047***	0.0061***
	(0.0035)	(0.0065)	(0.0011)	(0.0015)	(0.0035)	(0.0066)	(0.0011)	(0.0015)
Patent Registration	0.0138**	0.0258**	0.0045**	0.0059**	0.0155***	0.0290***	0.0050***	0.0066***
	(0.0056)	(0.0105)	(0.0018)	(0.0024)	(0.0056)	(0.0105)	(0.0019)	(0.0025)
Year Dummies	No	No	No	No	Yes	Yes	Yes	Yes
N	18981	18981	18981	18981	18981	18981	18981	18981

*p<.10, **p<.05, ***p<.01

[a] Standard errors are shown in parentheses. The full regression for column (2b) appears in column (2) of Table 7. All regressions include sales, percent capacity utilization, average wage, and dummy variables for firm's main product market expanding or declining. If year dummies are not included, the age of the firm is added to the regression.

[b] Marginal effects for the probability of being uncensored

[c] Marginal effects for the expected value of the dependent variable conditional on being uncensored

[d] Marginal effects for the unconditional expected value of the dependent variable

Table 4
Technological Change and Outsourcing, 1990-2002[a]
Using U.S. Patents as Proxy for Technological Change

A. Dependent Variable is Incidence of Outsourcing (Fixed Effect Logit Regressions)

	(1a) *Coeff*	*(1b)* *Mfx*	*(2a)* *Coeff*	*(2b)* *Mfx*
log (Patents)	0.6816***	0.1618***	0.7173*	0.1481**
	(0.1713)	(0.0415)	(0.3625)	(0.0677)
Year Dummies	No	No	Yes	Yes
N	11074	11074	11078	11078

B. Dependent Variable is Value of Outsourcing/Total Costs (Random Effect Tobit Regressions)

	(3a)	*(3b)*	*(3c)*	*(3d)*	*(4a)*	*(4b)*	*(4c)*	*(4d)*
		Marginal Effects				*Marginal Effects*		
	Coeff	*p(0,1)*[b]	*E(y|y>0)*[c]	*E(y*)*[d]	*Coeff*	*p(0,1)*[b]	*E(y|y>0)*[c]	*E(y*)*[d]
log (Patents)	0.0095***	0.0175***	0.0030***	0.0040***	0.0072***	0.0133***	0.0023***	0.0030***
	(0.0023)	(0.0043)	(0.0007)	(0.0010)	(0.0024)	(0.0044)	(0.0008)	(0.0010)
Year Dummies	No	No	No	No	Yes	Yes	Yes	Yes
N	18917	18917	18917	18917	18921	18921	18921	18921

*p<.10, **p<.05, ***p<.01

[a] Standard errors are shown in parentheses. Complete regression results are in Appendix Table A-2. All regressions include sales, percent capacity utilization, average wage, and dummy variables for firm's main product market expanding or declining. If year dummies are not included, the age of the firm is added to the regression.

[b] Marginal effects for the probability of being uncensored

[c] Marginal effects for the expected value of the dependent variable conditional on being uncensored

[d] Marginal effects for the unconditional expected value of the dependent variable

Table 5
Technological Change and Outsourcing, 1990-2002[a]
Dynamic Models Using U.S. Patents as Proxy for Technological Change

A. Dependent Variable is Incidence of Outsourcing

	(1a) *Coeff*	*(1b)* *Mfx*	*(2a)* *Coeff*	*(2b)* *Mfx*
log (Patents)	0.0244***	0.0058***	0.0271***	0.0064***
	(0.0092)	(0.0022)	(0.0093)	(0.0022)
lag of Outsourcing	2.0098***	0.4548***	2.0676***	0.4648***
	(0.0578)	(0.0118)	(0.0588)	(0.0119)
Outsourcing in year 1	1.7211***	0.4010***	1.7211***	0.4001***
	(0.0999)	(0.0212)	(0.1001)	(0.0212)
Year Dummies	No	No	Yes	Yes
N	17575	17575	17575	17575

B. Dependent Variable is Value of Outsourcing/Total Costs

	(3a)	*(3b)*	*(3c)*	*(3d)*	*(4a)*	*(4b)*	*(4c)*	*(4d)*
		Marginal Effects				*Marginal Effects*		
	Coeff	*p(0,1)*[b]	*E(y|y>0)*[c]	*E(y*)*[d]	*Coeff*	*p(0,1)*[b]	*E(y|y>0)*[c]	*E(y*)*[d]
log (Patents)	.0019***	0.0047***	0.0006***	0.0008***	0.0018***	0.0045***	0.0007***	0.0009***
	(0.0005)	(0.0012)	(0.0002)	(0.0002)	(0.0005)	(0.0012)	(0.0002)	(0.0002)
lag of Outsourcing/Costs	0.4802***	1.1692***	0.1515***	0.1957***	0.4787***	1.1660***	0.1509***	0.1949***
	(0.0129)	(0.0338)	(0.0041)	(0.0055)	(0.0130)	(0.0339)	(0.0041)	(0.0055)
Initial Outsourcing/Costs	0.3888***	0.9467***	0.1227***	0.1585***	0.3871***	0.9430***	0.1221***	0.1576***
	(0.0204)	(0.0502)	(0.0065)	(0.0086)	(0.0208)	(0.0512)	(0.0067)	(0.0088)
Year Dummies	No	No	No	No	Yes	Yes	Yes	Yes
N	16743	16743	16743	16743	16743	16743	16743	16743

*p<.10, **p<.05, ***p<.01

[a] Standard errors are shown in parentheses. Complete regression results are in Appendix Table A-3. All regressions include the mean values of sales, percent capacity utilization, average labor cost, and product market expansion or decline. If year dummies are not included, the age of the firm is added to the regression.

[b] Marginal effects for the probability of being uncensored

[c] Marginal effects for the expected value of the dependent variable conditional on being uncensored

[d] Marginal effects for the unconditional expected value of the dependent variable

Table 6
Technological change & Outsourcing, 1990-2002
The Effects of Relationship-Specific Inputs on the Incidence of Outsourcing[a]
Random Effects Logit Regressions

A. Including All Industries

	(1a)	(1b)	(2a)	(2b)
	Coeff.	Mfx	Coef.	Mfx
log (patents)	0.2382***	0.0537***	0.1764***	0.0393***
	(0.0582)	(0.0131)	(0.0585)	(0.0130)
Relationship-specific inputs			4.2505***	0.9463***
			(0.3267)	(0.0741)
N	19399	19399	18664	18664

B. Restricted to Firms in Industries with Below-Median Relationship-Specific Inputs

	(3a)	(3b)
	Coef.	Mfx
log (patents)	0.2556***	0.0465***
	(0.0848)	(0.0155)
N	13381	13381

* p<.10, ** p<.05, *** p<.01

[a] Standard errors are shown in parentheses. All regressions include year dummies, sales, percent capacity utilization, average wage, and dummy variables for firm's main product market expanding or declining. Relationship-specific investments are the percentage of the value of inputs that are neither reference priced nor sold on an organized exchange from Nunn (2007).

Table 7
Marginal Effects from Complete Logit Regressions, 1990-2002, and Restricted to 1990, 1994, 1998, 2002[a]

	1990-2002		1990, 1994, 1998 and 2002			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
R&D Activities	0.1328***	0.0725***	0.1109***	0.0878***	0.1311***	0.0870***
	(0.0166)	(0.0166)	(0.0185)	(0.0327)	(0.0182)	(0.0314)
Product Innovation	0.1310***	0.0486***	0.0849***	0.0635**	0.1009***	0.0629**
	(0.0145)	(0.0134)	(0.0182)	(0.0270)	(0.0178)	(0.0257)
Patent Registration	0.0840***	0.0463**	0.0843***	-0.0131	0.0885***	-0.0077
	(0.0227)	(0.0211)	(0.0265)	(0.0458)	(0.0265)	(0.0433)
Market Expanded	0.0561***	0.0078	0.0578***	0.0314	0.0645***	0.0304
	(0.0125)	(0.0124)	(0.0159)	(0.0237)	(0.0159)	(0.0225)
Market Declined	0.0167	0.0146	0.0289	0.0319	0.0320*	0.0271
	(0.0132)	(0.0135)	(0.0188)	(0.0282)	(0.0187)	(0.0267)
% Capacity Usage	0.0005	-0.0001	0.0006	0.0004	0.0004	0.0004
	(0.0004)	(0.0004)	(0.0005)	(0.0008)	(0.0005)	(0.0008)
Avg Labor Cost	0.0001	-0.0001	0.0034***	-0.0007	0.0037***	-0.0007
	(0.0001)	(0.0002)	(0.0008)	(0.0014)	(0.0008)	(0.0014)
Age of Firm	0.0013***		0.0008**		0.0009**	
	(0.0004)		(0.0004)		(0.0004)	
Sales	0.0646	-0.0756	0.0105	-0.1497	0.0241	-0.1509
(000000000 of Euros)	(0.0514)	(0.0849)	(0.0321)	(0.1818)	(0.0344)	(0.1756)
Digital machine tools			0.0275*	0.0207		
			(0.0157)	(0.0266)		
Robotics			0.0316	-0.0185		
			(0.0197)	(0.0337)		
Firm normally changes products			0.0946***	-0.0056		
			(0.0178)	(0.0284)		
Standard Product			-0.0188	-0.0614		
			(0.0183)	(0.0392)		
Exports/sales			0.0776**	0.1353		
			(0.0362)	(0.0921)		
Firm fixed effects	No	Yes	No	Yes	No	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Industry Dummies	Yes	No	Yes	No	Yes	No
N	19433	12267	6573	2311	6573	2311

* p<.10, ** p<.05, *** p<.01
[a] Standard errors are shown in parentheses. Robust standard errors clustered by firm are used in columns (1), (3) and (5). All regressions include year dummies. Variables are defined in the text and summary statistics are shown in Appendix Table A-1. Specification in column (2) corresponds to specification in column (2b) of Table 3.

Appendix Table A-1
Summary Statistics

Variable	Mean	Std. Dev.
Engaged in R&D activities	0.3748	0.4841
Firm normally changes product	0.2375	0.4256
Engaged in product innovation	0.2475	0.4316
Registered patents	0.0838	0.2771
Product is standardized	0.6292	0.4830
Market expanded	0.3396	0.4736
Market declined	0.1909	0.3931
Uses computer digital machine tools	0.4056	0.4910
Uses robotics	0.2181	0.4130
Average labor cost per employee (thousands of Euros)	25.960	12.222
Export value divided by sales	0.1640	0.2456
Age of firm	23.9305	22.536
Capacity utilization rate	81.8359	15.2313
Total Sales in 2002 (thousands of) Euros	47,200	195,700

Appendix Table A-2
Complete Regression Results for Corresponding Columns in Table 4[a]
Dependent Variable: Incidence of Outsourcing in (2a)- (2b) and Value of Outsourcing/Total Costs in (4a)-(4d)

	(2a)	(2b)	(4a)	(4b)	(4c)	(4d)
log of patents	0.7173**	0.1481**	0.0072***	0.0133***	0.0023***	0.0030***
	(0.3625)	(0.0677)	(0.0024)	(0.0044)	(0.0008)	(0.0010)
Market expanded	0.0464	0.0095	0.0144***	0.0266***	0.0047***	0.0061***
	(0.0597)	(0.0122)	(0.0033)	(0.0061)	(0.0011)	(0.0014)
Market declined	0.0692	0.0142	0.0050	0.0093	0.0016	0.0021
	(0.0664)	(0.0133)	(0.0037)	(0.0069)	(0.0012)	(0.0016)
% capacity usage	0.0008	0.0002	0.0004***	0.0006***	0.0001***	0.0001***
	(0.0021)	(0.0004)	(0.0001)	(0.0002)	(0.0000)	(0.0000)
Average labor cost	-0.0002	-0.0000	0.0000	0.0000	0.0000	0.0000
	(0.0009)	(0.0002)	(0.0000)	(0.0001)	(0.0000)	(0.0000)
Total Sales	-0.3031	-0.0626	0.0223**	0.0412**	0.0072**	0.0093**
(000000000 of Euros)	(0.3927)	(0.0813)	(0.0092)	(0.0171)	(0.0030)	(0.0039)
YearDummies	Yes	Yes	Yes	Yes	Yes	Yes
N	11078	11078	18921	18921	18921	18921

* p<.10, ** p<.05, *** p<.01
[a]Standard errors in parentheses.

Appendix Table A-3
Complete Regression Results for Corresponding Columns in Table 5[a]
Dependent Variable: Incidence of Outsourcing in (2a)- (2b) and Value of Outsourcing/Total Costs in (4a)-(4d)

	(2a)	(2b)	(4a)	(4b)	(4c)	(4d)
	Coeff.	Mfx	Coeff.	Mfx	Coeff	Mfx
log of patents	0.0271***	0.0064***	0.0018***	0.0045***	0.0006***	0.0007***
	(0.0093)	(0.0022)	(0.0005)	(0.0012)	(0.0002)	(0.0002)
If outsourced in t-1	2.0676***	0.4648***	0.4787***	1.1660***	0.1509***	0.1949***
	(0.0588)	(0.0119)	(0.0130)	(0.0339)	(0.0041)	(0.0055)
If outsourced in initial period	1.7211***	0.4001***	0.3871***	0.9430***	0.1221***	0.1576***
	(0.1001)	(0.0212)	(0.0208)	(0.0512)	(0.0067)	(0.0088)
Market Expand (mean)	0.7435***	0.1753***	0.0493***	0.1202***	0.0156***	0.0201***
	(0.1667)	(0.0393)	(0.0090)	(0.0219)	(0.0028)	(0.0037)
Market Decline (mean)	0.5084***	0.1199***	0.0288***	0.0700***	0.0091***	0.0117***
	(0.1901)	(0.0448)	(0.0105)	(0.0257)	(0.0033)	(0.0043)
% Capacity Usage (mean)	0.0150***	0.0035***	0.0011***	0.0027***	0.0003***	0.0004***
	(0.0037)	(0.0009)	(0.0002)	(0.0005)	(0.0001)	(0.0001)
Average labor cost (mean)	0.0028	0.0007	0.0003***	0.0007***	0.0001***	0.0001***
	(0.0018)	(0.0004)	(0.0001)	(0.0002)	(0.0000)	(0.0000)
Sales (mean)	0.3098*	0.0730*	0.0133	0.0324	0.0042	0.0054
(000000000 of Euros)	(0.1717)	(0.0405)	(0.0090)	(0.0218)	(0.0028)	(0.0036)
YearDummies	Yes	Yes	Yes	Yes	Yes	Yes
N	17575	17575	16743	16743	16743	16743

* p<.10, ** p<.05, *** p<.01
[a] Std. errors in parentheses