COMPETITION AND INNOVATION: AN INVERTED U RELATIONSHIP

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THE INSTITUTE FOR FISCAL STUDIES
WP02/04

Competition and Innovation: An Inverted U Relationship

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February 2002

Abstract

This paper investigates the relationship between product market competition (PMC) and innovation. A Schumpeterian growth model is developed in which firms innovate 'step-by-step', and where both technological leaders and their followers engage in R&D activities. In this model, competition may increase the incremental profit from innovating; on the other hand, competition may also reduce innovation incentives for laggards. This model generates four main predictions which we test empirically. First, the relationship between product market competition (PMC) and innovation is an inverted U-shape: the escape competition effect dominates for low initial levels of competition, whereas the Schumpeterian effect dominates at higher levels of competition. Second, the equilibrium degree of technological 'neck-and-neckness' among firms should decrease with PMC. Third, the higher the average degree of 'neck-and-neckness' in an industry, the steeper the inverted-U relationship between PMC and innovation in that industry. Fourth, firms may innovate more if subject to higher debt-pressure, especially at lower levels of PMC. We confront these four predictions with a new panel data set on UK firms' patenting activity at the US patenting office. The inverted U relationship, the neck and neck, and the debt pressure predictions are found to accord well with observed behavior in the data.

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1. Introduction[1]

Economists have long been interested in the relationship between product market competition (PMC) and innovation. Both the theoretical IO and the more recent endogenous growth literatures tackle the issue. The standard IO literature[2] predicts that innovation should decline with competition, as more competition reduces the monopoly rents that reward entry by new successful innovators. However, empirical work such as Geroski (1994), Nickell (1996) and Blundell, Griffith and Van Reenen (1999) has pointed to a positive correlation between product market competition and innovative output. Several theoretical attempts have been made to reconcile the Schumpeterian paradigm with the evidence provided in these studies, generating various predictions as to the shape of the relationship between PMC and innovation.[3] A first attempt, in Aghion-Dewatripont-Rey (1999), introduced the "competition as an incentive mechanism" argument in Hart (1983) into a Schumpeterian growth framework. This approach would still predict a monotonic relationship between PMC and innovation. This would be negative if most firms are value-maximizing and positive if most firms are governed by "satisficing" managers who mainly care about the firm remaining in

[1] **Acknowledgement:** The authors would like to thank Daron Acemoglu, Tim Bresnahan, Wendy Carlin, Paul David, Janice Eberly, Dennis Ranque, Robert Solow, Manuel Trajtenberg, Alwyn Young, John Van Reenen and participants at the CIAR seminar for their comments. Financial support for this project was provided by the ESRC Centre for the Microeconomic Analysis of Fiscal Policy at the IFS. The data was developed with funding from the Leverhulme Trust.

[2] See, inter alia, Dasgupta-Stiglitz (1980) and also the first generation of Schumpeterian growth models (Aghion-Howitt (1992), Caballero-Jaffe (1993)).

[3] See Aghion-Howitt (1998), Chapter 7, for a survey of some of these these attempts.

business. In addition, this model would predict substitutability between PMC and debt-financing together with hard budget constraints, in the sense that more debt-financing in a hard budget environment could substitute for PMC in inducing otherwise reluctant managers to innovate more frequently in order to keep their firm afloat. This latter finding has been questioned however in recent empirical work by Grosfeld-Tressel (2001) and Aghion-Carlin-Schaffer (2002).

An alternative approach, introduced by Aghion-Harris-Vickers (1997) and subsequently analyzed in Aghion-Harris-Howitt-Vickers (2001), extends the basic Schumpeterian model by allowing incumbent firms to innovate. In these models, innovation incentives depend not so much upon post-innovation rents per se, but more upon the difference between post-innovation and pre-innovation rents (the latter were equal to zero in the basic model where all innovations were made by outsiders). In this case, more PMC may end up fostering innovations and growth as it may reduce a firm's pre-innovation rents by more than it reduces its post-innovation rents. In other words, competition may increase the incremental profits from innovating, and thereby encourage R&D investments aimed at "escaping competition"; and it will do so to a larger extent in more "neck-and-neck" industries, that is in industries in which oligopolistic firms face more similar production costs; the firm with lower (resp. higher) unit costs is referred to as the technological leader (resp. follower) in the corresponding industry.

In this framework firms innovate in order to reduce production costs, and they do it "step-by-step", in the sense that a laggard firm in any industry must first catch up with the technological leader before becoming itself a leader in the

future. In neck-and-neck industries competition is particularly intense and it is also in those industries that the "escape competition" effect pointed out above is strongest. On the other hand, in less neck-and-neck, or more "unleveled", industries, more competition may also reduce innovation as the laggard's reward to catching up with the technological leader may fall (this is a "Schumpeterian effect" of the kind emphasized in the earlier models). Finally, by increasing innovation incentives relatively more in neck-and-neck industries than in unleveled industries, an increase in product market competition will tend to reduce the fraction of neck-and-neck industries in the economy; this "composition effect" reinforces the Schumpeterian effect in inducing a negative correlation between PMC and aggregate productivity growth or the aggregate rate of innovations.

The paper begins with the derivation of four main empirical predictions of this "step-by-step innovation" model, which we then confront with data from a panel of UK firms. We argue that the changes in product market competition and the extensive level of patenting across industries over the last thirty years in the UK make it a particularly interesting environment to assess these predictions. The first prediction is that the relationship between PMC and innovation is an *inverted-U shape*: that is, the escape competition effect tends to dominate for low initial levels of competition, whereas the Schumpeterian effect tends to dominate at higher levels of PMC. This prediction is in line with an earlier conjecture by Scherer (1965). The second prediction is that the equilibrium degree of neck-and-neckness should decrease with PMC, as more PMC will increase innovation incentives comparatively more in neck-and-neck sectors, thereby reducing the ex-

pected time interval during which an industry remains "neck-and-neck". Third, the higher the average degree of neck-and-neckness of an economy, the stronger the escape competition effect will be on average and therefore the steeper the positive part of the inverted-U relationship between PMC and innovation. Fourth, this model predicts that the escape competition effect should also be stronger in industries where firms' managers face harder budget constraints. As a result, firms with higher debt/cash-flow ratios may innovate more for any level of PMC.

These predictions are examined across a range of industries drawn from a firm panel for the UK. The data are on UK listed firms over the period 1968-1996 and include information on costs, sales, investments and the number of successful patent applications at the US patent office. Detailed information on citations are used to weight our measure of patents granted for each firm in each year. We derive a measure of product market competition using a Lerner index. A sequence of competition policy reforms, that differ in their impact across industries, are used to argue that the Lerner index provides a reliable measure of changes in product market competition over the period we study. These policy reforms are further used as instruments to control for the potential endogeneity in the Lerner index. Within each industry we construct a measure of the size of technology gap (degree of neck and neckness) based on the dispersion of firm level technology and cost indicators. We have matched information at the industry level from the US and other OECD countries which we use to provide further exogenous instruments for the technological gap between leaders and followers across industries. Finally, the long time series on firms in each industry allow us to control for industry level

effects as well as common time effects that plague cross-section and time series analyses of these relationships.

The theoretical discussion provides a specification for the average arrival rate of innovations in an industry according to the level of product market competition and the degree of neck-and-neckness. Our empirical specification starts with a model for the hazard rate for patenting and uses this to derive a generalised Poisson model for the count of patents, which is our main measure of innovative activity. Since we are interested in investigating whether there is a non-monotonic relationship between innovation and product market competition we adopt a semiparametric approach and begin our analysis using a hazard rate specification which is an exponential polynomial spline function in our competition measure. As part of this empirical investigation we find an exponential quadratic model fits the data extremely well once industry and time effects are allowed for.

A striking finding is of a strong inverted U relationship. This single peaked relationship is robust to many alternative specifications and to the endogeneity of the Lerner index. Controlling for endogeneity and including time and industry effects shifts the peak toward the competitive direction but still suggests the importance of the Schumpeterian effect for a large minority of firms and industries. This inverted U relationship continues to hold when we split by the degree of neck-and-neckness. It is robust to controlling for firm size and for fixed capital costs. This inverted U relationship is also found in the data for many individual industries.

The rest of the paper is structured as follows. Section 2 lays out the basic theoretical framework. Section 3 derives our main predictions analytically in the special case of a maximum technological gap equal to one. Section 3 simulates the general model with unbounded gaps. Section 4 concludes the theoretical part by summarizing our main empirical predictions. Section 5 provides a description of the data and assesses the degree to which the variables used are likely to provide good measures of their theoretical counterparts developed in the earlier sections of the paper. In section 6 we present our main empirical findings. We first analyze the robustness of the inverted U relationship and then go on to examine how this relationship varies with the size of the technology gap between firms within the industry (the degree of neck and neckness) and with debt pressure. We find a strong accordance between the main theoretical predictions and the empirical results. Section 7 provides a short summary and concludes with directions for further research.

2. A theoretical framework

2.1. Consumers

Suppose that the representative consumer has a utility function of the form:

$$u = \int_0^1 \ln x_i di, \tag{2.1}$$

where each x_i is an aggregate of two goods produced by duopolists in sector i,[4] defined by the subutility function:

$$x_i = v(x_{Ai}, x_{Bi})$$

where v is homogeneous of degree one and symmetric in its two arguments. We shall be particularly interested in the case:

$$x_i = (x_{Ai}^{\alpha_i} + x_{Bi}^{\alpha_i})^{\frac{1}{\alpha_i}} \tag{2.2}$$

where a higher $\alpha_i \in (0, 1]$ reflects a higher degree of substitutability between the two inputs in industry i.

The log-preference assumption made in (2.1) implies that in equilibrium individuals spend the same amount on each basket x_i. We normalize this common amount to unity by using expenditure as the numeraire for the prices p_{Ai} and p_{Bi} at each date. Thus the representative household chooses each x_{Ai} and x_{Bi} to maximize $v(x_{Ai}, x_{Bi})$ subject to the budget constraint: $p_{Ai}x_{Ai} + p_{Bi}x_{Bi} = 1$.

In the special case where $v(x_{Ai}, x_{Bi}) = (x_{Ai}^{\alpha_i} + x_{Bi}^{\alpha_i})^{\frac{1}{\alpha_i}}$, the demand functions facing the two firms in industry i are:

$$x_{Ai} = \frac{p_{Ai}^{\frac{1}{a_i-1}}}{p_{Ai}^{\frac{\alpha_i}{a_i-1}} + p_{Bi}^{\frac{\alpha_i}{a_i-1}}} \quad \text{and} \quad x_{Bi} = \frac{p_{Bi}^{\frac{1}{a_i-1}}}{p_{Ai}^{\frac{\alpha_i}{a_i-1}} + p_{Bi}^{\frac{\alpha_i}{a_i-1}}}. \tag{2.3}$$

For notational simplicity we suppress the notation for the industry index i from here on.

[4] See Aghion-Howitt (2002) for variants of this model with N firm- industries and free entry.

2.2. Technology levels, R&D and innovations

Each firm produces using labor as the only input,[5] according to a constant-returns production function, and takes the wage rate as given. Thus the unit costs of production c_A and c_B of the two firms in an industry are independent of the quantities produced. Now, let k denote the technology level of duopoly firm j in some industry i; that is, one unit of labor currently employed by firm j generates an output flow equal to:

$$A_j = \gamma^{k_j}, \qquad j = A, B, \tag{2.4}$$

where $\gamma > 1$ is a parameter that measures the size of a leading-edge innovation; (equivalently, it takes γ^{-k_j} units of labor for firm j to produce one unit of output). An industry is then fully characterized by a pair of integers (l, m), where l is the leaders technology and m is the technology gap of the leader over the follower. We define π_m(respectively π_{-m}) to be the equilibrium profit flow of a firm m steps ahead of (respectively behind) its rival.[6]

For expositional simplicity we shall first concentrate on the simple case where knowledge spillovers between leader and follower are such that the maximum sustainable gap is $m = 1$. That is, if a firm is one step ahead and it innovates the

[5] In Aghion et al (2001) we argue that the model can be easily extended to the case where firms use both capital and labor as inputs according to a CES production technology of the form:

$$x_j = (\alpha k_j^{\frac{\sigma-1}{\sigma}} + (1-\alpha)(A_j l_j)^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}},$$

where A_j measured labor productivity in firm j and is mutiplied by $\gamma > 1$ each time firm j innovates.

[6] The above logarithmic technology along with the cost structure $c(x) = x.\gamma^{-k}$ implies that the profit in the industry depends only on the gap m between the leader and follower, and not on absolute levels of technology.

follower will automatically copy the leader's previous technology and so remain only one step ahead. Therefore, in that case, given that profitability is only dependent on the gap between leader and follower, no innovation will be undertaken by the leader. At any point in time there will therefore be two types of sectors in the economy: leveled sectors where firms are neck and neck, that is $m = 0$, and unleveled sectors where one firm is leading the other in the same industry, with $m = 1$.

We denote by $\psi(n) = \frac{1}{2}\beta n^2$ the R&D cost (in units of labour) of a leader (resp. follower) firm moving one technological step ahead with a Poisson hazard rate of n[7]. Let n_m denote the research intensity put up by each firm in an industry with technological gap m, and let n_{-m} denote the innovation rate or R&D intensity of the follower in such an industry.

2.3. Bellman equations

Let V_m denote the steady state value of being currently a leader (or follower if $m < 0$) in an industry with technology gap m, and let w denote the wage rate, which we take as given assuming an infinitely elastic supply of labour. We then have the following Bellman equations:

$$\begin{aligned} rV_m &= \pi_m + n_m(V_{m+1} - V_m) + n_{-m}(V_{m-1} - V_m) - w\beta(n_m)^2/2; \\ rV_{-m} &= \pi_{-m} + n_m(V_{-m-1} - V_{-m}) + n_{-m}(V_{-m+1} - V_{-m}) - w\beta(n_{-m})^2/2; \end{aligned}$$

[7] In Aghion et al (2001) we analyze a different model in which the laggard in an industry with technological gap m catches up immediately with the technological leader whenever she innovates, thereby reducing her unit labor cost by γ^{-m}. This alternative formulation however tends to exaggerate the importance of the "escape competition" effect and to downplay the schumpeterian effect of PMC.

$$rV_0 = \pi_0 + n_0(V_1 - V_0) + n_0(V_{-1} - V_0) - w\beta(n_0)^2/2;$$

In words, the annuity value rV_m of currently being a technological leader in an industry with gap m at date t equals the current profit flow π_m minus the current R&D cost $(w\beta {n_m}^2/2)dt$, plus the discounted expected capital *gain* $n_m(V_{m+1} - V_m)$ from making an innovation and thereby moving one further step ahead of the follower, minus the discounted expected capital *loss* $n_{-m}(V_{m-1} - V_m)$ from having the follower catch up by one step with the leader. The equation for the annuity value of a follower is similarly explained. Finally, in the Bellman equation for a neck-and-neck firm, note that if each firm only takes into account its own cost of R&D, in symmetric Nash equilibrium both R&D efforts are equal.

Now, using the fact that each firm chooses its own R&D effort to maximize its current value, i.e to maximize the RHS of the corresponding Bellman equation, we obtain the first order conditions:

$$\begin{aligned} \beta w n_m &= V_{m+1} - V_m; \beta w n_{-m} = V_{-(m-1)} - V_{-m}; \\ \beta w n_0 &= V_1 - V_0. \end{aligned}$$

2.4. Product-market competition

Boone (2001) makes the convincing argument that any parameter increase that would result in increasing the relative profit shares of more advanced firms, that is the profitability of a greater technological lead, would be a suitable measure of product market competition. Thus one possible (inverse) measure of competition, especially in the $m \leq 1$ case, would be the profit flow of "neck-and-neck" firms,

π_0, with a higher π_0 resulting from higher collusion among otherwise similar firms in the same sector.

Another potential "measure" of competition from Boone's theoretical standpoint, is the elasticity of substitution parameter α in the case:

$$v(x_A, x_B) = (x_A^\alpha + x_B^\alpha)^{\frac{1}{\alpha}}.$$

More specifically, assume that in any sector the two duopolists in that sector compete in prices, arriving at a Bertrand equilibrium. According to the demand functions in (2.3), the elasticity of demand faced by each firm j is $\eta_j = (1 - \alpha\lambda_j) / (1 - \alpha)$, where $\lambda_j = p_j x_j$ is the firm's revenue:

$$\lambda_j = \frac{p_j^{\frac{\alpha}{\alpha-1}}}{p_A^{\frac{\alpha}{\alpha-1}} + p_B^{\frac{\alpha}{\alpha-1}}}, \ j = A, B. \tag{2.5}$$

Thus each firm's equilibrium price is:

$$p_j = \frac{\eta_j}{\eta_j - 1} c_j = \frac{1 - \alpha\lambda_j}{\alpha(1 - \lambda_j)} c_j, \ j = A, B \tag{2.6}$$

and its equilibrium profit is:

$$\Pi_j = \frac{\lambda_j}{\eta_j} = \frac{\lambda_j (1 - \alpha)}{1 - \alpha\lambda_j}, \ j = A, B \tag{2.7}$$

Equations (2.5) $\sim$ (2.7) can be solved for unique equilibrium revenues, prices and profits. Given the degree of substitutability α, the equilibrium profit of each firm j is determined by its relative cost $z = c_j / c_{-j}$; an equiproportional reduction in both c_A and c_B would induce each firm to reduce its price in the same proportion, which, because industry demand is unit-elastic, would leave the equilibrium

revenues and profits unchanged. More formally, (2.5) $\sim$ (2.7) implicitly define a function $\phi(z, \alpha)$ such that:

$$\Pi_A = \phi(c_A/c_B, \alpha) \text{ and } \Pi_B = \phi(c_B/c_A, \alpha). \tag{2.8}$$

The substitutability parameter α is our measure of the degree of product market competition in each industry. The limiting case of $\alpha = 0$ defines the minimal degree of competition; the opposite limiting case of $\alpha = 1$ is the case of Bertrand competition between undifferentiated products, which results in perfect competition when the two firms have the same unit cost. Although α is ostensibly a taste parameter, it can be shown to satisfy Boone's requirement.[8] Furthermore, in this model α corresponds to standard measures of competition. For example, it is a monotonically increasing transformation of the elasticity of substitution in demand $\left(\frac{1}{1-\alpha}\right)$ between the two rivals' outputs in the industry. Given a firm's share λ of industry revenue, α is also a monotonically increasing transformation of the elasticity of demand $\frac{1-\alpha\lambda}{1-\alpha}$ faced by the firm. Furthermore, given a firm's industry share λ, α is a monotonically decreasing function of the firm's Lerner index:

$$LI = \frac{1-\alpha}{1-\alpha\lambda}. \tag{2.9}$$

In our empirical analysis, we shall use the Lerner index itself as a measure of PMC, being aware that this index also depends upon the firm's market share λ[9].

[8] See Aghion et al (2001) for a formal proof.

[9] The following considerations, suggest that the average Lerner index of a random sample of firms in an industry should be a decreasing function of the α measure of PMC, even after taking into account the effect of α on R&D intensities and therefore on average market shares. First,

2.5. The one-step case

In the special case where the maximum technological gap between leaders and followers is $m = 1$, assuming for simplicity that $w = \beta = 1$[10], and using the fact that in that case a technological leader has no incentive to invest in R&D ($n_1 = 0$), the above Bellman equations become:

$$\left.\begin{aligned} rV_1 &= \pi_1 + n_{-1}(V_0 - V_1) \\ rV_{-1} &= \pi_{-1} + +n_{-1}(V_0 - V_{-1}) - (n_{-1})^2/2 \\ rV_0 &= \pi_0 + n_0(V_1 - V_0) + n_0(V_{-1} - V_0) - (n_0)^2/2 \end{aligned}\right\} \tag{2.10}$$

with corresponding first order conditions:

$$\left.\begin{aligned} n_{-1} &= V_0 - V_{-1} \\ n_0 &= V_1 - V_0 \end{aligned}\right\} \tag{2.11}$$

Thus, for example, the annuity value rV_1 of being a leader is the current flow of profit π_1 minus the expected capital loss per unit of time from being caught up with by the laggard. The expected loss is the loss in value $V_1 - V_0$ that will occur if the laggard innovates, multiplied by the flow probability n_{-1} of the laggard innovating.

for λ sufficiently small (which is typically the case in practice), the Lerner index LI is clearly decreasing in α; second, we show in the Appendix that for small innovation size γ a firm's Lerner is approximately linear in the firm's lead size, so that when averaging across the two firms in the same industry, we approximately get the Lerner index of a neck-and-neck firm (with $\lambda = 1/2$), which itself is decreasing in α; third, when we calculate the expected Lerner index of a randomly selected firm under the steady-state distribution of lead size, using the parameters underlying our simulations in section 4, we again find that the average Lerner index is a decreasing function of α.

[10] We thus take the wage rate as given, with the implicit assumption of an infinitely elastic supply of labor at wage $w = 1$. See Aghion et. al (1997) for a discussion of the case where the supply of labor is inelastic.

2.6. Individual innovation intensities

Equations (2.10) and (2.11) solve for n_{-1} and n_0. Eliminating the V's between these equations yields the reduced form research equations:

$$\frac{(n_0)^2}{2} + rn_0 - (\pi_1 - \pi_0) = 0 \tag{2.12}$$

$$\frac{(n_{-1})^2}{2} + (r + n_0)n_{-1} - (\pi_0 - \pi_{-1}) - \frac{(n_0)^2}{2} = 0. \tag{2.13}$$

This system is recursive, as the first quadratic equation solves for n_0, and then given n_0 the second quadratic equation solves for n_{-1}. We obtain:

$$n_0 = -r + \sqrt{r^2 + 2(\pi_1 - \pi_0)} \tag{2.14}$$

$$n_{-1} = -(r + n_0) + \sqrt{(r + n_0)^2 + n_0^2 + 2(\pi_0 - \pi_{-1})}. \tag{2.15}$$

Combining (2.14) and (2.15) yields the alternative expression:

$$n_{-1} = -(r + n_0) + \sqrt{r^2 + (n_0)^2 + 2(\pi_1 - \pi_{-1})}. \tag{2.16}$$

Here, we shall focus on the effects of an increase in product market competition as represented by a reduction in π_0 leaving π_{-1} and π_1 unchanged. (The analysis and results in the remaining part of this section can be replicated using the elasticity parameter α as an alternative way to parametrize PMC). We immediately see that n_0 increases whereas n_{-1} can be shown to fall.[11] The latter effect (on n_{-1}) is the basic Schumpeterian effect that results from reducing the rents that can be

[11] >From (2.14):

$$\frac{\partial n_0}{\partial \pi_0} = -\frac{1}{\sqrt{r^2 + 2(\pi_1 - \pi_0)}} < 0$$

>From this and (2.16):

captured by a follower who succeeds in catching-up with its rival by innovating.[12] The former effect (on n_0) is what we refer to as an "escape competition effect", namely that more competition induces neck-and-neck firms to innovate in order to escape competition, as the incremental value of getting ahead is increased with higher PMC. Thus, if we were to treat the fractions of leveled and unleveled sectors in the economy as an exogenous parameter, we would get the conclusion that the higher the fraction of neck-and-neck sectors in the economy, the more positive the effect of product market competition on the average innovation rate. This complementarity between PMC and neck-and-neckness will appear more clearly in Section 3 below when we simulate the general model with unbounded gaps.

2.7. Average innovation rate

An increase in product market competition will have an ambiguous effect on the *steady-state* aggregate innovation rate because it will induce more frequent innovations in currently neck-and-neck sectors and slower innovations in currently unleveled sectors. The overall effect on the average innovation rate and on average productivity growth will depend on the steady-state fraction of time a sector

$$\frac{\partial n_{-1}}{\partial \pi_0} = \frac{\partial n_0}{\partial \pi_0}\left[-1 + \frac{n_0}{\sqrt{r^2 + (n_0)^2 + 2(\pi_1 - \pi_{-1})}}\right] > 0$$

[12] As we will see when we allow for m arbitrarily large, this Schumpeterian effect may be counteracted by a "forward looking" escape competition effect. More PMC induces a laggard in a sector with small technological gap (between the leader and that laggard) to increase its R&D investment in order to enter the race for a large technological lead sooner. This and the Schumpeterian effects together give rise to an inverted U-shape relationship between n_{-m} and PMC as measured by α for all $m < 0$ (see section 3.2 below).

spends being neck-and-neck.

More formally, let μ_1 (resp. μ_0) denote the steady-state probability of being an unleveled (resp. neck-and-neck) industry. During any unit time interval, the steady-state probability that a sector moves from being unleveled to leveled is $\mu_1 n_{-1}$, and the probability that it moves in the opposite direction is $2\mu_0 n_0$. In steady state, these two probabilities must be equal:

$$\mu_1 n_{-1} = 2\mu_0 n_0.$$

This, together with the fact that:

$$\mu_1 + \mu_0 = 1,$$

implies that the average flow of innovations is:

$$I = \mu_0 2n_0 + \mu_1 n_{-1} = 2\mu_1 n_{-1} = \frac{4n_0 n_{-1}}{2n_0 + n_{-1}}. \tag{2.17}$$

Figure 1 shows a numerical example in which $r = .04, \pi_{-1} = 0, \pi_1 = 10, w = \beta = 1$. *As* π_0 *decreases* from $\pi = \pi_1$, *the innovation rate* I *follows an inverted-U shaped pattern.*

2.8. The logic of the inverse-U

The reason for the inverted-U shape is that when there is not much product market competition, π_0 is close to π_1, so that there is hardly any incentive for firms to innovate when the sector is leveled, and the overall innovation rate will be highest when the sector is unleveled and there is asymmetric competition. Thus the industry will be quick to leave the unleveled state (which it does as soon as the

laggard innovates) and slow to leave the leveled state (which won't happen until one of the neck-and-neck firms innovates), and as a result the industry will spend most of the time in the unleveled state. Hence when competition intensifies, the effect on the economy-wide average rate of innovation will be determined by what happens in the leveled state. But we have seen that the effect of more intense competition on the innovation rate $2n_0$ in a leveled industry is positive, since the "escape competition" effect is at work for firms in that state. In other words, if the degree of competition is very low to begin with, an increase will result in a faster average innovation rate.

On the other hand, when competition is very high, π_0 is close to π_{-1} and there is relatively little incentive for the laggard in an unleveled state to innovate, especially if the rate of interest is high, because the incremental profit is very low. (Of course there is still an incentive for the laggard to innovate even if $\pi_0 = \pi_{-1}$, because, although an innovation will not raise current profits, it will take the firm one step closer to possibly attaining a leader's profit π_1.) Thus the industry will be relatively slow to leave the unleveled state. Meanwhile the large incremental profit $\pi_1 - \pi_0$ gives firms in the leveled state a relatively large incentive to innovate, so that the industry will be relatively quick to leave the leveled state. As a result, the industry will spend most of the time unleveled, so that when competition intensifies the effect on the average rate of innovation may be determined by what happens in the unleveled state. But we have seen that the effect of more intense competition on the innovation rate in the unleveled state is negative, since the Schumpeterian effect is at work on the laggard while the leader never innovates.

In other words, if the degree of competition is very high to begin with, an increase may result in a slower average innovation rate.

Hence the possibility of an inverse-U relationship between competition and innovation. When competition is low, an increase will raise innovation through the escape competition effect on neck-and-neck firms, but when it becomes intense enough it may lower innovation through the Schumpeterian effect on laggards. The reason why one effect dominates when competition is low and the other when competition is intense is the "composition effect" on the steady-state distribution of technology gaps.

To see this composition effect more clearly note that in the steady state distribution:

$$\mu_0 = \frac{n_{-1}}{n_{-1} + 2n_0} \qquad \text{and} \qquad \mu_1 = \frac{2n_0}{n_{-1} + 2n_0}$$

In the limit when there is no competition ($\pi_0 = \pi_1$), (2.14) implies that $n_0 = 0$, so that in the steady state the industry is always leveled ($\mu_0 = 1$), whereas when there is the maximum competition ($\pi_0 = \pi_{-1}$), (2.14) and (2.16) imply that $n_0 > n_{-1}$, so that the overall rate of innovation in the leveled state is more than twice that in the unleveled state and as a result the fraction of time μ_0 spent leveled in steady state is less than 1/3.

2.9. Debt pressure and product market competition

In this subsection we explore the interplay between product market competition and debt pressure indicators- such as debt-exposure (and the resulting probability of incurring bankruptcy costs) and the magnitude of default costs (which one

could interpret as reflecting the hardness of firms' budget constraints). We show the possibility that higher debt pressure and/or higher default costs could induce firms to innovate more in order to escape debt pressure.

To formalize the interplay between competition and the exposure to bankruptcy costs, we consider the following variant of the basic one-step model: (1) neck-and-neck profit flows $\widetilde{\pi}_0$ are random, i.i.d over time and uniformly distributed over the interval $[\pi_0, \pi_0 + 1]$; (2) $\pi_{-1} \equiv 0; \pi_1$ constant with $\pi_1 >> \pi_0 + 1$; (3) firms finance their investments through debt financing, which we define here as involving a fixed flow repayment obligation D, a flow default cost f incurred per period of time by the firm whenever $\widetilde{\pi}_0 < D$.[13]

Consider first the case where exit costs are negligible and where $D \in (\pi_0, \pi_0 + 1)$; then, the Bellman equations for equilibrium R&D investments, can be expressed as:

$$\begin{aligned} rV_1 &= \pi_1 - D + n_{-1}(V_0 - V_1); \\ rV_0 &= \psi(\pi_0, D, f) + n_0(V_1 - V_0) + n_0(V_{-1} - V_0) - n_0^2/2, \\ rV_{-1} &= -f + n_{-1}(V_0 - V_{-1}) - (n_{-1})^2/2. \end{aligned}$$

where

$$\psi(\pi_0, D, f) = \int_D^{\pi_0+1} (u - D)du - f \int_{\pi_0}^{D} du,$$

is the expected flow utility of a manager in a new industry, net of the expected

[13] This formulation is inspired from the costly state verification literature (e.g Townsend (1979), Gale-Hellwig (1985)) on debt-financing, in which firms' revenues are assumed to be unverifiable by outside investors, unless they incur a flow verification cost f . For simplicity, we abstract in this section from firms' choice over the optimal financial contract.

verification costs. From these Bellman equations and the corresponding first order conditions, we obtain the following expression for the equilibrium neck-and-neck firm's innovation rate:

$$n_0 = -r + \sqrt{r^2 + 2(\pi_1 - D - \psi)} = -r + \sqrt{\delta}, \tag{2.18}$$

where we re-express ψ as:

$$\psi = \frac{1}{2}(\pi_0 + 1 - D)^2 - f(D - \pi_0).$$

Hence:

$$\frac{\partial n_0}{\partial \pi_0} = -\left(\pi_0 + 1 - D + f\right)/\sqrt{\delta} < 0. \tag{2.19}$$

Suppose first that the default cost f is constant. Then, provided f is large enough we find that the effect of increasing the firm's leverage D, will be to raise innovation. That is:

$$\frac{\partial n_0}{\partial D} = \left(\pi_0 - D + f\right)/\sqrt{\delta}$$

which is positive if $f > D - \pi_0$. Thus, for any level of PMC, higher debt pressure as measured by a higher level of D will result in more R&D by neck and neck firms.

Consider next the effect of an increase in the default cost f, which we interpret as a hardening of the firm's budget constraint. We immediately have:

$$\frac{\partial n_0}{\partial f} > 0,$$

that is, a higher cost of default induces firms to innovate more in order to escape the threat of bankruptcy.

3. The general model

In principle, one can solve the general model, but closed form solutions are hard to derive when m is large, and the best one can do is to solve it numerically. Figure 2 depicts the values as a function of α, which we now use to parametrize PMC, for the case where $r = .1, \gamma = 1.75, w = 1, \beta = 15$. The larger α, that is the higher the degree of PMC, the higher the curvature of the logistic V_m function as a function of m at the neighborhood of $m = 0$.

3.1. Industry innovation rate

Using the same equations, we can also characterize the relationship between α and the individual innovation rates n_m and $n_{-m} + h$ (where h is a help parameter which reflects the fact that it might be easier for laggards than for leaders to go one technological step forward). Figure 3 depicts the relationship between α and total intra-industry innovation rates (n_m+ n_{-m}), for the above parameter values and for $h = 0.025$. We see an inverted-U shaped pattern for $m \neq 0$, which in turn results from the interplay between the "escape competition" and Schumpeterian effects of PMC on innovation incentives. We also see that innovation intensities are higher and also increase more rapidly with α in the case of neck-and-neck firms. Thus, *there is complementarity between PMC and the degree of neck-and-neckness* as measured by how small m is. The relationship between PMC and innovation becomes increasingly steeper as m goes down, i.e as the industry becomes more neck-and-neck.

3.2. Industry structure and steady-state innovation/growth rates

In the equilibrium we define μ_m to be the steady state fraction of time the industry spends with technological gap m. We obviously have:

$$\sum_m \mu_m = 1$$

In addition, the following equations must also hold in steady-state:

$$\mu_m(n_m + n_{-m} + h) = \mu_{m-1} n_{m-1} + \mu_{m+1}(n_{-(m+1)} + h),$$

for all $m \geq 2$. The LHS of this equation represents the flow probability of exiting technological gap (or "state") m; the RHS represents the flow probability of entering state m, both, from state $(m-1)$ with the leader innovating, and from state $(m+1)$ sectors with the follower innovating. For $m = 1$ we have:

$$\mu_1(n_1 + n_{-1} + h) = 2\mu_0 n_0 + \mu_2(n_{-2} + h),$$

as two firms instead of one can turn a neck-and-neck sector into an unleveled sector with technological gap $m = 1$.

And for $m = 0$, we simply have:

$$2\mu_0 n_0 = \mu_1(n_{-1} + h).$$

In other words, a neck-and-neck sector becomes unleveled whenever a firm in that sector innovates, and only state-1 sectors can become neck-and-neck whenever the laggard in that sector innovates. Figure 4 depicts μ as a function of m and α. We see that *on average the industry becomes increasingly neck and neck as PMC increases.*

Now, we can compute the average rate of productivity growth for the industry. In the general case where the lead size m can take any integer value, one can show that the average growth rate of the industry is equal to:

$$g = (2\mu_0 x_0 + \sum_{k \geq 1} \mu_k x_k) \ln \gamma. \tag{G}$$

Equation (G) states that the growth rate equals the product of the frequency of "frontier innovations" (innovations by the industry leader or a neck-and-neck firm, which advance the industry's frontier technology) and the (log) size of innovations. Figure 5 depicts g as a function of α. *We again obtain an inverted U-shape.*

4. Summary of theoretical predictions

We now conclude the theoretical part of the paper by stating four main predictions that came out of our analysis in the previous sections, and which we test in the empirical part of the paper:

1. The relationship between product market competition and the average innovation rate, is an inverted-U shape.

2. The expected technological gap in an industry increases as product market competition increases, that is the distribution shifts towards a lower probability of being neck-and-neck.

3. There is a complementarity between product market competition and the degree of neck-and-neckness of an industry. The closer firms are in technology space (the more neck-and-neck firms are in that industry) the steeper

the positive effect of product market competition on innovation and the larger the average number of innovations.

4. Firms with higher debt/cash-flow ratios may innovate more for any level of PMC.

5. Data and Measurement Issues

The empirical investigation that we report in the next section is based on a panel of UK companies covering the period 1968-1997. The UK over this period provides an extremely rich environment within which to study the impact of product market competition on innovation behaviour. Not only is there a long panel of detailed company data but this period also saw a number of significant, and largely exogenous, changes in product market competition. These changes, which altered the structure of product market competition across industries, included the implementation of the European Single Market Program, a series of structural and behavioural reforms imposed on different industries as a result of investigations by the Monopolies and Mergers Commission (MMC) under the Fair Trading Act and large scale privatisations. We document these in more detail below and relate them carefully to our measure of industry level product market competition. We will also argue that they provide a powerful set of instrumental variables for our competitiveness measure.

There are two main data sources used in this study - firm level accounting data and administrative data from the US patents office.[14] These allow us to

[14] This data was developed with funding from the Leverhulme Trust. See Bloom and Van

combine information on technological performance, revenues, labour costs and capital costs. The accounting data come from Datastream and include all firms quoted on the London Stock Exchange between 1968 and 1997.[15] The firm level patenting information from the US Patent Office dataset was matched to a subset of the firms for which accounting data is available. We have patents data for all firms with a name beginning A-L (plus all large R&D firms) that were listed on the London Stock Exchange any time between 1983 and 1985. These have been matched to all of their subsidiaries in 1985.[16] This data runs from 1968-1996 and contains 461 firms with 236 firms that patent.

In order to test the predictions detailed in section 5 we need measures of firms' innovative output, the degree of product market competition in an industry, the size of the technology gap between firms within an industry (how "neck-and-neck" firms are) and the extent of bankruptcy threat facing each firm. We will discuss these in turn.

5.1. Measuring innovation

There is a large literature on measuring innovation intensity. The most commonly used measures at the firm level are research and development spending, patenting activity, innovation counts and total factor productivity. Although R&D expen-

Reenen (2000) for a more detailed description of the data.

[15] We removed firms with missing values on sales, capital or employment, firms with less than three consecutive observations, observations for firms with abnormal length accounting periods (we drop firms whose accounting period falls outside 300 to 450 days due to changes in accounting year ends) and exclude observations for firms where there was a jump of greater than 150% in any of the key variables (capital, labour, sales).

[16] This matching has been done by hand in order to achieve a higher match rate than with computer matching.

diture is available in the UK and we use it to check the robustness of our results, it is not mandatory for firms to report it, and prior to 1990 it is frequently not reported. We do not use total factor productivity (TFP) as a measure of innovative activity either because of the well known problem that commonly used measures of TFP are themselves biased in the presence of imperfectly competitive product markets.[17] For these reasons our main measure is based on information on patents taken out by UK firms in the US patent office. Our data includes information on all patents taken out by a randomly selected sample of 461 UK stock market listed firms (all firms with names beginning A-L).[18]

The US patenting office is the place where innovations are patented internationally. These patents can be based on research conducted anywhere in the world. We also have information on citations to and from these patents. One concern that is often expressed about using patent counts is that patents may not be comparable across firms or industries because their value can vary significantly. Therefore, we use the number of times a patent has been cited by other patents to weight the patent and thus provide a measure that is more indicative of the value of the patent.[19] We can extend the interpretation of our results for patents to productivity growth as patents are well known to have a strong effect on productivity growth.[20] This has also been demonstrated directly for our dataset by Bloom and

[17] See, inter alia, Hall (1988), Klette and Griliches (1996) and Klette (1999).

[18] As we highlight below the complete set of UK stock market firms is used to construct the other industry measures we require.

[19] Hall, Jaffe and Trajtenberg et al. (2001) use the US Patent Office patenting data set to examine the effects of patenting on the market value of US firms.

[20] See for example the survey of the patenting literature in Griliches (1990).

Van Reenen (2001) who find a highly significant response of productivity to both patents and patent citations. Figure 5.1 presents a frequency histogram of annual firms level patent count. This picture excludes the 37% of zero observations. It also truncates the distribution at 50 patents per year per firm. As we note further below there are a few very large patenting firms our data. The inclusion of fixed effects in our empirical model reflects the argument that certain firms and certain industries may have a higher propensity to patent than others and that this may not be not causally related to the competitive structure of the firm or industry.

5.2. Measuring the degree of product market competition

The degree of product market competition is measured at the industry level. We use the firm level data to construct these industry level measures. We use information reported in Datastream which we have for all UK stock market listed firms. As discussed in Section 2.3 our main indicator of product market competition is the Lerner Index or price cost margin. In fact we use 1 minus the Lerner, so a value of 1 indicates perfect competition (price equals marginal cost) while values below 1 indicate some degree of market power. This measure has several advantages over measures such as market shares or a Herfindahl or concentration index. In order to measure any of those it is necessary to have a definition of both the geographic and product boundaries of the market in which the firm operates. This is particularly important in our application as many innovative UK firms operate in international markets, so that traditional market concentration

measures could be extremely misleading.[21]

In accordance with our theoretical measure the Lerner index is taken to be constant within industry. Firms in our data can operate in many industries. We classify firms by the 2-digit SIC code in which the firm had the largest proportion of its sales in 1995. For 33% of the firms this represented all of their sales. The median share of sales accounted for by the largest industry is 90%. We use the entire sample of Datastream firms to estimate the industry Lerner Index. We use accounting data to construct a firm level measure similar to Nickell (1996)'s measure of rents over value-added. The Lerner Index is price minus marginal cost over price. One difficulty we face is that we do not observe marginal cost. For the numerator we use operating profits net of depreciation and provisions. This is more like price minus average cost. We divided this by sales.

$$li_{it} = \frac{\text{operating profit (DS137)}}{\text{sales (DS104)}}.$$

There are several concerns we might have about this measure. First, in UK accounts capital depreciation, R&D expenditure and advertising have been deducted. In theory we would like to deduct R&D depreciation (rather than expenditure), but this is not available and we note that in steady state investment in the R&D stock should equal depreciation.[22] Second, the assumption that $AC \approx MC$

[21] One example of the difficulties in using concentration indexes is provided by the pharmaceutical industry, which accounts for about 10% of global R&D. In the UK the pharmaceutical industry is dominated by two large players, GlaxoSmithKline and AstraZeneca, whose sales accounts for about 65% and 30% of the market. But these firms are global players, competing with other US and European firms. In global terms they have market shares of 7% and 4%, with these low market shares reflect the fierce competition in the industry. In this case, without global market sales, concentration measures would be extremely misleading.

[22] For growing firms investment will be greater than depreciation so our estimate of Lerner

assumes away any significant fixed costs of production.[23] We would like to deduced the financial cost of capital from the numerator, but we do not observe this. In the empirical analysis we consider the robustness of our results to the deduction of an estimate of the cost of finance (cost of capital*capital) from our measure of profits.[24]

Our industry measure of product market competition, denoted c_{jt}, is an unweighted average across all firms in the industry,

$$c_{jt} = 1 - \frac{1}{N_{jt}} \sum_{i \in j} li_{it}$$

where i indexes firms, j indexes industry, t index time and N_{jt} is the number of firms in industry j in year t.

We also use an alternative competition measure α as described in (2.9). This strips out the affect of market share on a firms' profit-margin,

$$\alpha_{it} = \frac{1 - li_{it}}{1 - ms_{it} * li_{it}}$$

We use the firm's share of output produced by firms in the same 2-digit industry on the London Stock Market to measure market share. This is not our prefered measure because of our concerns about measuring market shares of firms operating in international markets, as discussed above. This adjustment and the results of it are discussed further in the presentation of the empirical results. They also help

Index will be an underestimate of the true markup.

[23] More precisely, we assume that there is no correlation between significant fixed costs and innovation in our econometric approach which could lead us to erroneously find an inverted U shape. We are grateful to Robert Barro for pointing this out.

[24] Where the cost of capital is assumed to be 0.085 for all firms and time periods and capital stock is measured using the perpetual inventory method.

to back up the analysis in the Appendix which develops a theoretical argument as to why the Lerner and α should be inversely related even after allowing for market share to adjust to changes in the competitive environment.

We are able to measure the Lerner index using information on all UK firms in Datastream, not only the sample for which we also observe patents. For firms operating in more than one market the Lerner Index will represent a weighted average of the degree of product market competition across these markets. This could lead to measurement error and attenuation bias. We discuss this further in the empirical section below. Figure 5.2 presents the time path of the Lerner index and our estimate of alpha for six of the manufacturing industries used in the study.[25] This shows a wide variation in the index over time that differs systematically across industries.

One of our main concerns is that the Lerner may be endogenous to the patenting decision. We address this problem in a number of ways. Our main approach is to use a number of 'policy' instruments that provide exogenous variation in the degree of industry wide competition. These instruments are described below and we show that their relationship to the Lerner suggests that the Lerner index is picking up variation in industry wide product market competition. In the empirical analysis we use the instruments to correct our estimators for endogeneity in the Lerner index. All instrument sets include industry and time effects. We also use the lagged value of the Lerner index. Added to these are the set of policy

[25] Extraction of other minerals (23), Chemical industry (25), Manufacture of office machinery (33), Electrical and electronic (34), Motor vehicles and parts (35), Food (41).

instruments discussed in section 5.2.

Before using the Lerner in our detailed econometric analysis we consider the extent to with the variation in our Lerner measure reflects changes in the degree of competition. In order to do this we consider a set of major policy event that affected the degree of competition. These are of three sorts - the EU Single Market Programme, Monopoly and Merger Commision investigations that resulted in structural or behaviours remedies being imposed on the industry, and privatisations. The table below lists the sic codes and years affect by these policies:

Policy instruments		
	SIC	**Years**
SMP high	see appendix	1988
SMP medium	see appendix	1988
Cars	351	1984, 1987, 1988
Car Parts	353	1982, 1987
Periodicals	475	1987
Brewing	427	1986
Telecoms	344	1981, 1984, 1989
Textiles	430	1989
Razors and Razor blades	316	1990
Steel	220	1987
Ordnance	329	1987

In Appendix B we provide more detail on the policies and the industries that were affected.

5.3. Technology gap

We are also interested in looking at how the size of the technology gap between firms within an industry interacts with the degree of product market competition. We measure this by the proportional distance a firm is from the technological fron-

tier, as measured by total factor productivity. This corresponds to the parameter m introduced in section 2.2,

$$m_i = \frac{TFP_F - TFP_i}{TFP_F} \tag{5.1}$$

where F denotes the frontier (the highest TFP) and i denotes non-frontier firms. For the frontier firm (if they are in our sample) our measure is

$$m_F = \frac{TFP_F - TFP_{F-1}}{TFP_F} \tag{5.2}$$

where $F-1$ denotes the firm just behind the frontier. A lower value of m indicates that firms are technologically close (so the industry is more neck and neck) while a high value of m indicated a large technology gap, so the industry is more unleveled. In the empirical application below we use an industry level measure that is the average across firms in the industry

$$m_{jt}^{tfp} = \frac{1}{N_{jt}} \sum_{i \in j} m_{it}$$

where N_{jt} is the number firms in industry j at time t. We measure TFP using a first order approximation (Cobb-Douglas). We using information at on TFP in the US, Japan and Germany at the industry-year level to capture the foreign frontier.

5.4. Data description

Table 1 shows the number and proportion of observations where we have both accounting and patents data and where we have only accounting data. On average we observe patents data for 34% of the complete Datastream sample. We do not

include industries where we have fewer than three firms or where there were no patents throughout the period 1968-1996. Our sample contains 330 firms with 4,500 observations over the period 1971-1994 in seventeen 2-digit industries. Of these there are 236 patenting firms, with around 60,000 patents in total which account for around 200,000 citations.

Table 2 shows the average of the firm level Lerner Index for the sample of firms where we have only accounting data and for the sample where we have both accounting and patents data. The table shows that the firms we have in our sample are similar in terms of their Lerner Index to those not in our sample - both are used to construct our industry measure of the Lerner. At the industry level the Lerner averages 8% and ranges from 21% in Extraction of other minerals in 1976 to 3% in Motor Vehicles in 1981.

Table 3 presents the descriptive statistics on our sample of 330 firms. >From this we can see that, firstly, our patent count is highly skewed with most firms taking out no patents in any given year but one firm (ICI in 1974) taking out 409 patents. Also, the employment figures give an indicator of the size of our firms with about 1,500 employees in the median firm, while the median of 17 observations per firm reflects the long time series of our data set.

Our measure of the technology gap (neck and neck) also has a large spread ranging from industries in which leaders and follower firms all have very similar levels of TFP (those with measures close to 0) to industries in which the leader is far ahead of the rest of the industry (those with measures close to 1).

Our financial pressure variable is debt payments over operating profits plus

depreciation. This also shows a similarly large spread between firms in which debt repayments consume all their cash flow (a pressure measure of 1) to those with little or no debt (a pressure variable of 0).

6. Empirical Support for the Inverted U

Earlier analysis using UK company data (Blundell, Griffith and Van Reenen 1995,1999) established two empirical regularities. First, market share is a significant positive determinant of innovation intensity at the firm level even after controlling for fixed effects, for endogeneity of market share and for firm size. Second, industry competition measures, including industry concentration and import penetration show positive and significant competition effects. This work also found that at the industry level the competition effect dominated. This concurs with other empirical studies based on UK company data, in particular that by Nickell (1996).

Our aim is to take this research forward by assessing the non-monotonicity of the relationship between innovation intensity and product market competition.

6.1. A Method of Moments Estimator

The theoretical discussion in sections 2 and 3 generate a relationship between product market competition and the innovation hazard. Denoting c as our measure of competition, we can express this as

$$n = e^{g(c)}. \tag{6.1}$$

Suppose the patent process has a Poisson distribution with hazard rate (6.1). The resulting *count* of patents in any time interval has the probability distribution

$$\Pr[p = k|c] = e^{g(c)k} e^{-e^{g(c)}}/k! \tag{6.2}$$

and the expected number of patents satisfies

$$E[p|c] = e^{g(c)}. \tag{6.3}$$

Parametric models that study count data processes typically base their specification on this Poisson model with a known (linear) form for $g(c)$ but relax the strong variance assumption underlying (6.2).[26] The Poisson MLE is a consistent estimator in this case but overdispersion, common in innovation and patent data sets, implies that the estimated variance covariance matrix is incorrect. To correct for this a heteroscedasticity corrected variance covariance matrix can be used which adjusts for the presence of overdispersion.[27] We follow this approach in our empirical analysis but, because we are particularly interested in investigating the shape of relationship between product market competition and patents, we adopt a semiparametric generalisation.

In our data firms $i = 1, ...N_t$ are grouped into J mutually exclusive industries with $i \in I_j$ with $j = 1, ..., J$. We observe firms for $t = 1, ..., T_i$ periods. Our aim is to model average innovation behaviour by industry and relate it to the competition measure. Our principle competition measure (c_{jt}) is measured at the industry level while patents (p_{it}) are measured for each firm. As noted above our

[26] See Griliches, Hall and Hausman(1984).
[27] See Blundell, Griffith and Windmeijer (1999).

measure c_{jt} is calculated using a larger sample (the population of Stock Market listed firms) than is used in estimation. Following from the specification of the conditional mean (6.3) we write

$$E[p_{it}|c_{jt}] = e^{g(c_{jt})} \tag{6.4}$$

where $g(c)$ is of unknown form. This directly identifies the innovation hazard (6.1). Note also that (6.4) is fully nonparametric but will be extended into a semiparametric specification as we introduce more conditioning variables into the mean specification.

It is very likely that firms in different industries will have observed levels of patenting activity that have no direct causal relationship with product market competition but reflect other institutional features of the industry. Consequently industry fixed effects are essential to remove any spurious correlation or 'endogeneity' of this type. Time effects are also included to remove common macro shocks. Conditional on industry and time, average patent behaviour is related to industry competition according to

$$E[p_{it}|c_{jt}, x_{jt}] = e^{\{g(c_{jt})+x_{it}^{'}\beta\}} \tag{6.5}$$

where x_{it} represent a complete set of time and industry dummy variables.

The moment condition (6.5) can be used to define an appropriate semiparametric estimator and in the analysis below we approximate $g(c)$ with a polynomial spline function.[28] Given this specification, and without introducing any firm level

[28] See Ai and Chen (2001).

covariates, moment condition (6.5) refers specifically to an industry level average relationship. However, we will include certain firm level covariates in some specifications, for example measures of firm size and firm level fixed effects. Consequently we will present all estimations using firm level regressions.

Finally we note that our actual dependent variable is a citation weighted count of patents. This is used so as to 'correct' the patent measure for the importance of the innovation. We maintain the same mean specification and same estimation approach.

6.2. The Basic Inverted U Relationship

As we do not wish to impose any prior restrictions on the shape of $g(c)$ in (6.5) we begin our analysis using a polynomial spline. The result of this polynomial spline regression without any conditioning variables is presented in Figure 6.1a.[29] The two curves plotted in the figure represent a quadratic spline[30] and a simple quadratic specification for $g(c)$. It is interesting to note that the simple quadratic representation of $g(c)$ provides a reasonable approximation and both specifications show a clear inverted U. The underlying distribution of the data is shown by the intensity of the points on the estimated curves. These indicate that the peak of the inverted U lies towards the left of the median of the distribution (the median is 0.92). The estimated coefficients for the quadratic model are presented in Table 4. As a further specification check on the overall shape of this relationship we

[29] The relationship between citation weighted patents and 1 - Lerner is evaluated at the median year and industry.

[30] With four evenly spaced knot points at 0.86, 0.89, 0.92 and 0.95.

also present the simple kernel regression of p on c in Figure A6.1(a)[31] once again confirming an inverted U shape.

[Table 4 ABOUT HERE]

Figure 6.1b uses the same polynomial spline specification as in Figure 6.1a but includes the time and industry dummies. This displays an inverted U but with the peak much shifted to the right. It also shows that the basic shape is robust to the exclusion of these dummy variables. The direction of the shift is to be expected. Industries that have a higher level of patenting may also be associated with more concentrated firms, biasing the results against the competitive story. Once we condition on industry dummies the competition effect comes in stronger. Figure A6.1c in Appendix A presents the same curves with 95% confidence bands. It is clear that the inclusion of the time and industry effects results in the (exponential) quadratic providing a very close approximation which is not significantly different from the more flexible spline representation.

The inclusion of industry and time effects makes the competition effect on innovation more pronounced. From Figure 6.1b we can see that a simple linear relationship would yield a positive slope, clearly not the case in Figure 6.1a. This analysis confirms the results presented in Nickell (1996) which documents the positive (linear) impact of industry level competition on innovation in a model using firm level UK data and including industry and time effects.

[31] Using a kernel with bandwidth 0.025 and Gaussian weights. We also found a similar U shape using Epanechnikov weights, which has its entire support lying within a finite bandwidth unlike the Gaussian Kernel.

This inverted U relationship is also persevered when we consider each industry separately. Figure 6.1c presents the relationship fitted separately for each of the top four innovating industries in our sample. In each case there is an inverted U shape with observations on either side of the peak.

In section 6.3 below we consider controlling for endogeneity in the Lerner index using the instruments described in section 5.5. We show that the inverted U is robust to endogeneity in the Lerner. In the remainder of this section we consider a number of further robustness checks. First we control for the size of the firm by including beginning of period capital stock in the exponent term of the conditional mean. Figure 6.2a shows that this does little to impact on the results. Next we consider the impact of adjusting our Lerner measure of competition for fixed capital costs. This is done by removing a factor proportional to the observed value of capital stock in each firm as described in section 5.2. Figure 6.2b presents the results for this adjusted measure of industry competition. It shows precisely the same shape - a clear inverted U. A key point here is that the entire curve shifts to the right. Accounting for differences in capital intensity does not change the shape of the curve. As an additional check we consider removing the measure of firm market share from the Lerner index using the observed market share data and the particular expression for α implicit in the Lerner index (2.9). The results are presented in Figure 6.2c and again the overall relationship remains in place.

In section 5.1 we noted that in the UK R&D expenditure was not widely reported in firms' accounts before 1990. Nonetheless we use it as a robustness check. We have 1,162 observations from 1980 - 1994. In 1980 only six firms in our

data reported R&D. From 1990 over 150 firms report R&D. We estimate a model of the form

$$\ln(R\&D)_{it} = g(c_{jt}) + x_{it}^{'}\beta + u_{it}. \tag{6.6}$$

Figure 6.2d plots the $g\,(c_{jt})$ function as above, and shows that the inverted U results is preserved.

Together these results seem to substantiate the first main prediction from the theory.

6.3. Technological Gap and Product Market Competition.

The empirical analysis presented so far has studied the impact of product market competition at the industry level on the level of patenting activity. We now look at the importance of similarities in technology across firms in the same industry - defined by the size of the technology gap or the degree of neck and neckness. An argument derived from the theoretical discussion in section 2 is that in equilibrium the technology gap should be an increasing function of the overall level of industry wide competition (so neck and neckness should be a decreasing function). This constitutes the second of the main theoretical predictions.

To measure the technological gap within any industry at any point in time, we use a measure the distance of each firm from the frontier firm as described in section 5.3. We label this measure m, a lower value of m indicates that the technological gap is smaller (so firms are more neck and neck). Figure 6.3 presents a kernel smoothed plot of m for each industry time observation against the industry

competition index. This shows a strongly positive relationship as predicted by the theory.

A further theoretical prediction concerns the form of the inverted U shape relationship among those industries where the technology gap is small. This is the third of the predictions listed in section 4. To assess this we split our sample into those with above median technological gap and those below - these are called less neck and neckness and more neck and neck respectively. Figure 6.4 presents a picture of the same quadratic specification as in Figure 6.1b but with this split. For comparison the quadratic specification in Figure 6.1b is also reproduced and is represented by the thin line. Two features stand out clearly. First, more neck and neck industries have a higher level of innovation activity. Second, the inverted U shape is still pronounced in both groups. It is steeper for the more neck and neck industries, and we can see that the density lies more to the left of peak in more neck and neck industries. This accords well with the theoretical simulations presented in section 3. These differences and the overall shape are highly significant as can be seen from the confidence bands presented in Figure A6.4 in Appendix A.

6.4. Endogeneity

The inclusion of industry and time effects may not be sufficient to remove all spurious correlation between the competition measure and the average patent count. These dummies remove unobservable time and industry level effects, so all that could remain are relative changes in the competition measure across industries

in the UK that are indirectly caused by shocks to UK patents. To remove such temporal correlation we use the policy instruments described in section 5.2. In addition we include a full set of time and industry effects and also consider the use of lagged values of the Lerner index. These turn out to be good instruments in the sense that they are strongly correlated with the UK industry level competing measure we use.

We adopt a control function approach.[32] This differs from standard IV (and GMM) in nonlinear models.[33] The idea is to use functions of the residuals from the regression of the competition index on the instruments as controls in an extended version of the moment condition.

Without loss of generality we write our underlying stochastic model for patents as

$$p_{it} = e^{\{g(c_{jt}) + x_{it}^{'}\beta\}} u_{it}. \tag{6.7}$$

Exogeneity of c and x implies

$$E[u_{it}|c_{jt}, x_{jt}] = 1 \tag{6.8}$$

resulting in the moment condition (6.5). Under endogeneity of c this moment condition on u_{it} no longer holds. However, we assume we have instruments z_{it} that obey the reduced form

$$c_{jt} = \pi(z_{jt}) + x_{it}^{'}\gamma + v_{jt} \tag{6.9}$$

[32] See Newey, Powell and Vella (1998).
[33] See Blundell and Powell (2001).

with

$$E[v_{it}|z_{it}, x_{jt}] = 1 \tag{6.10}$$

The control function assumption[34] states

$$E[u_{it}|c_{jt}, x_{jt}, v_{it}] = 1 \tag{6.11}$$

so that controlling for v_{it} in the conditional moment condition is sufficient to retrieve the conditional moment assumption. In estimation we use the extended moment condition (6.4)

$$E[p_{it}|c_{jt}, x_{jt}, v_{jt}] = e^{\{g(c_{jt})+x_{it}^{'}\beta+\rho(v_{jt})\}} \tag{6.12}$$

The assumption being that inclusion of some function of the reduced form residuals v_{jt}, say just ρv_{jt}, is sufficient to remove all spurious correlation and recover the correct structural relationship $g(c)$.[35] More precisely, we can integrate over the distribution of v and recover the 'average structural function'

$$e^{\{g(c_{jt})+x_{it}^{'}\beta\}} = \int e^{\{g(c_{jt})+x_{it}^{'}\beta+\rho v_{jt}\}} dF_v \tag{6.13}$$

Empirically this is achieved using the empirical distribution for v.[36]

For the exponential quadratic specification of g we generalize this slightly by including the reduced form residuals for the linear and quadratic term in c. Indeed, if the model were quadratic rather than exponential quadratic this approach would

[34] See Blundell and Powell (2001).

[35] The inclusion of control function terms in a grouped regression model with group and time dummies as a method of dealing with endogeneity is discussed further in Blundell, Duncan and Meghir (1998).

[36] See Blundell and Powell (2001).

recover exactly the standard instrumental variable estimator for the quadratic model using the instruments z_{it}. A simple test for endogeneity, conditional on the time and fixed effects x_{jt}, is given by $H_0 : \rho = 0$.[37]

6.5. Endogeneity Results

There are two sources of endogeneity we consider. The first concerns the Lerner index itself. For this we use the policy instruments detailed in section 5.5. We also include measures of R&D intensity in the US and in France matching by industry. These instruments work well. The p-values for the instruments in the reduced form regressions for the Lerner index and the Lerner index squared are presented in Table 4. The policy instruments can be seen to play a direct and significant role. The impact on our results of controlling for endogeneity in the Lerner index using the control function approach and these instruments is presented in Figure 6.5a. This is directly comparable with Figure 6.4 but now all lines are adjusted for endogeneity using this control function approach. If anything the results are now stronger with a clear inverted U and a much stronger impact of overall competition for industries where firms are close in technology space. These differences remain significant as can be seen from the confidence bands presented in Figure A6.5a.

A further source of endogeneity may come from the neck and neck split. To allow for this we follow a similar control function approach. As instruments we use the following instruments: (i) Imports from the OECD over output in France and the USA, varies over industry and time, levels and squared terms. (ii) Output

[37] See Blundell and Smith (1986).

minus costs over output in France and the USA, varies by industry and time, levels and squared terms. (iii) Estimate of markup from Martins et al (1996) for France and the USA, varies by industry, interacted with time trend. (iv) TFP in France and the USA, varies by industry and time, levels and squared terms. (v) R&D over output in France and the USA, varies by industry and time, levels and squared terms.The impact of controlling for the endogeneity of the sample separation between high and low neck and neck industries is presented in Figure 6.5b. The strong positive impact of high neck and neck industries is further increased and the inverted U shape remains.

6.6. Financial pressure

Our fourth theoretical prediction is that higher debt pressure should reinforce the escape competition effect of PMC and thereby enhance innovation incentives especially at lower levels of PMC. We use a measure of firms' debt to cash flow ratio, as described in section 5.4, to split firms. We identify the 40% of firms with the highest debt payments to cash flow ratio as "high" and compare those to "low" debt to cash flow firms. In Figure 6.6a we show the relationship between product market competition and these two groups, as before the solid line is as shown in Figure 6.1b. We have allowed the intercept and the coefficients on the Lerner and Lerner squared to vary across the groups. First, we notice that firms with higher financial pressure innovate more on average than those with lower financial pressure, as predicted by the theory. Secondly, we note that the escape competition effect dominates over a larger range of values for the Lerner for high

financial pressure firms, again, as predicted by the theory.

In Figure 6.6b we control for potential endogeneity of the Lerner as described above. Our findings are robust to these controls.

7. Conclusions

This paper provides a first attempt at confronting theory with data on the relationship between product market competition and the innovation rate. Our empirical results confirm the existence of an inverted U-shaped relationship between product market competition and innovations, which in turn indicates that some kind of an "escape competition" effect should dominate at lower levels of PMC as measured by the Lerner index, whereas the "Schumpeterian effect" pointed out in earlier endogenous growth models and before that in the IO literature, should dominate at high initial levels of PMC. Our results also indicate a similar inverted U-shaped relationship at the industry level, and that it tends to be steeper for firms that are more neck-and-neck and/or that are closer to the leading-edge in their industry. Finally, we find that firms facing a higher threat of bankruptcy are subject to a stronger escape competition effect and innovate more on average, especially at lower levels on competition.

We plan to extend our analysis in two directions. The first is to examine more carefully the timing of the changes in product market competition and their impact on innovation. This will cover two aspects of dynamics. One is the dynamics of the production process of innovations (e.g. incorporating adjustment costs or an error correction component) and the other to consider the history and

institutional aspects of specific industries.

The second extension would be to introduce entry and entry threat as alternative (or complementary) measures of competition. This again would be done using an extension of the above model with entry and exit in any industry. Preliminary simulations performed on this extended model suggest: (i) an inverted U-shaped relationship between potential entry and the innovation rate; (ii) a strategic complementarity between entry and PMC, in the sense that the escape competition effect of PMC on the aggregate innovation/growth rate, appears to be stronger the higher the level of entry.

8. Appendix A

Here we provide the details of two reasons for believing that, according to the theory outlined in the first part of the paper, the average Lerner index of a random sample of firms in an industry should be a decreasing function of the α measure of competition.

The first reason is that for the special case when γ is close to 1 then the average of the 2 Lerner indexes in an industry with any lead size m is well approximated by $\frac{1-\alpha}{1-\alpha/2}$, which is the Lerner of a neck-and-neck firm and is strictly decreasing in α. The proof of this proposition goes as follows.

As asserted in the text, the Lerner index of a firm with lead size m is:

$$L_m = \frac{1-\alpha}{1-\alpha\lambda\left(\gamma^{-m},\alpha\right)} \equiv \widetilde{L}\left(\gamma^{-m},\alpha\right)$$

where $\lambda\left(z,\alpha\right)$ is the market share of a firm with relative cost z, defined implicitly by equations (2.5) and (2.6) of the text. When $m = 0$ the proposition holds exactly:

$$L_0 = \frac{1-\alpha}{1-\alpha/2}$$

because $\lambda\left(1,\alpha\right) = 1/2$. So suppose $m \lesseqgtr 0$. Taking a Taylor expansion around $\gamma = 1$ and defining $\varepsilon \equiv \gamma - 1$, we have:

$$L_m = L_0 - \varepsilon m \left.\frac{\partial \widetilde{L}\left(z,\alpha\right)}{\partial z}\right|_{z=1} + O\left(\varepsilon^2\right)$$

Therefore the average of the two firms' Lerner indexes is:

$$\left(L_m + L_{-m}\right)/2 = L_0 + O\left(\varepsilon^2\right) = \frac{1-\alpha}{1-\alpha/2} + O\left(\varepsilon^2\right).$$

So, when gamma is small, *whatever the distribution of* m, the expected Lerner of a randomly selected firm is approximately the same decreasing function of alpha.

The second reason is that even when γ is not small, when you sample firms whose lead sizes are distributed according to the steady state distribution μ of the

theory, numerically the expected value of the randomly selected firm is a decreasing function of α. This is illustrated below in Figure A1, which plots the expected value of a firm's Lerner index under the distribution μ against the industry's α. The parameter values are the same as those underlying Figures $2 \sim 5$ in the text. Figure A1 also plots the approximate value $\frac{1-\alpha}{1-\alpha/2}$ analyzed in the preceding paragraphs, which continues to be the actual Lerner index of a neck-and-neck firm, and which continues to approximate the theoretical prediction of the average Lerner fairly closely when α is small.

9. Appendix B: Policy instruments

9.1. Single Market Program

The EU Single Market Programme (SMP) is used as an exogenous policy instrument that affected the degree of product market competition. The aims of the SMP were to bring down internal barriers to the free movement of goods, services, capital and labour. The European Commission's White Paper (1985) outlined around three hundred specific measures which were designed to achieve this.

Mayes and Hart (1994) summarise these measures into six main areas of action: (1) unified market in goods and services, (2) unified factor market, (3) promotion of competition, (4) monetary integration, (5) social protection, and (6) united response to external challenges. The measures included harmonising indirect taxes, standards, border controls, lowering the barriers which enable firms to segment markets, thus increasing both the size of the markets and the intensity of competition (e.g. remove nationality requirements, common competition policy, removal of other non-tariff barriers); removal of public sector discrimination in favour of its own firms; reducing the cost of capital and labour by permitting free flow across countries and to assist the process of structural change by investing in infrastructure, technology and human skills (see Burridge and Mayes (1992)).

The measures that were aimed at promoting competition include instituting common rules on regulation, takeovers, state assistance to industry, patents and copyrights, company accounting and disclosure of information, opening up of pub-

lic procurement to competitive tender and reducing intervention in agriculture. This wide range of measures impacted upon different industries differentially. The Cecchini report attempted to quantify the size of non-tariff barriers in existence before the SMP was implemented. They use a series of surveys and technical papers to assign numerical values to the size of non-tariff barriers in each industry before the SMP. Industries are divided into three categories by the Cecchini report (the classification used here is from Mayes and Hart (1994, p53) of 3-digit industries that were likely to be affected by the SMP):

(i) barriers were low pre-SMP so the impact of the SMP was expected to be low,

(ii) an intermediate level of barriers pre-SMP and where the measures undertaken as part of the SMP were expected to significantly reduce them:

247 Glass
248 Refractory and ceram
251 Basic industrial che
321 Agricultural machine
322 Metal-worked machine
323 Textile machinery
324 Processing machinery
327 Machinery for wood,
346 Domestic electric ap
347 Electric lamps
351 Motor vehicles and e
352 Motor vehicle bodies
353 Motor vehicle parts
427 Brewing and malting
428 Soft drinks
431 Woollen
432 Cotton and silk
438 Carpets
451 Footwear
453 Clothing

455 Household textiles

481 Rubber

(iii) those where there were high level of barriers pre-SMP and the SMP was expected to significantly reduce them:

256 Specialised chemical

257 Pharmaceutical produ

325 Mining and construct

326 Power transmission e

328 Other machinery

330 Office machinery

330 Manufacture of offic

341 Insulated wires

342 Basic electrical equ

344 Telecomm equipment

345 Other electronic equ

361 Shipbuilding

362 Railway and tramway

371 Precision instrument

372 Medical equipment

373 Optical instruments

421 Ice cream chocolate

491 Jewellery

494 Toys and games

The initial SMP programme was announced in 1986 and implementation was scheduled to take place starting in 1988 and be completed by 1992 (although not all proposals had been implemented by 1992). Thus three time periods are considered:

PRE 1980-1987, pre-SMP

DUR 1988-1992, during implementation of SMP

AFT 1993-1996, after SMP implemented

Griffith (2001) uses plant level data in the UK to show that the impact of the SMP was to increase product market competition (bring down the Lerner Index)

in those industries that were expected ex ante to be affected. Markups in the intermediate industries came down by around 5% and in the industries with high barriers they came down by over 10%.

9.2. Cars

MMC (1982) reported on the possible existence of a complex monopoly in the wholesale supply of car parts. The report concluded that car manufacturers and importers restricted competition by requiring persons to whom they supplied car parts to acquire them exclusively from them or from sources approved by them. This limited the extent to which component manufacturers could compete with each other and with car manufacturers and importers, restricted price competition, imposed some limitation on the level of services from which the franchised sector could benefit, and restricted competition among factors. An Order[38] was subsequently approved making it unlawful for car manufacturers and importers to insist on their franchised dealers buying car parts exclusively from them.

There were four major privatisations in the car industry. Jaquar, a luxury car maker, was sold in 1984 (fixed price offer of 100% of shares). Unipart, a suppiler of parts and accessories to Rover, was sold in a mangement buyout in 1987. Leyland, a manufacturer of buses, trucks and vans, was sold in 1987 (combination of a management buyout and sale to existing firms). Rover, a vehicle manufacturer, was sold to British Aerospace in 1988.

9.3. Periodicals

MMC (1988) found that publishers of specialist magazines intended for campers climbers and walkers refused to accept advertisements containing prices and that this constituted a complex monopoly. The adverse effects were thought to be: (a) hindering or preventing readers' informed choice, (b) restriction of competition between specialist retailers and mail order companies, (c) narrowing of price

[38] HC Hansard 24, 26-May-82, c 314-315 ORDERS SI 1982 : 1146 The Restriction On Agreements (Manufacturers And Importers Of Motor Cars) Order

ranges and increase of average price level. An Order[39] prohibiting such actions was implemented.

9.4. Brewing

MMC (1989) found a complex monopoly in the brewing industry. The adverse effects were identified as: a) inhibition of new entry; b) reduced competition; c) higher or discriminatory prices; d) reduced consumer choice; e) restrictions on the independence of tenants of pubs; f) pricing structure which adversely affected wholesalers.

Action taken[40] requiring national brewers to free half of their premises in excess of 2000 from ties. This meant that pubs were able to choose a guest beer. This applied to all brewers ensuring easy exit from loan ties, requiring brewers to supply beer at maximum published wholesale prices, and stopped brewers selling premises with conditions that prevented them from being used as a pub in the future. There was a review of the licensing system to see whether magistrates should in future only take account of whether applicants are "fit and proper. Following consultation with the EC two Orders were passed. The Tied Estate Order was concerned with measures applying to national brewers, in particular national brewers were required to free half of their premises in excess of 2,000 from ties by 1.11.92, also, all those tied by national brewers, whether through loan ties or tenancies, were to be free to choose a guest beer, low alcohol beer, soft drinks and some other drinks from any source by 1.5.90. The Loan Ties, Licensed Premises and Wholesale Prices Order applied to all brewers and ensured easy exit from loan ties, required brewers to supply beer at maximum published wholesale prices and stopped brewers selling premises with conditions that prevented them from being used as pubs in the future. The impact of these orders on firms pricing behaviour has subsequently been studied by Slade (2001).

[39] ORDERS SI 1988 : 1017 The Restriction on Conduct (Specialist Advertising Services) Order

[40] ORDERS SI 1989 : 2258 The Supply of Beer (Loan Ties, Licensed Premises and Wholesale Prices) Order; SI 1989 : 2390 The Supply of Beer (Tied Estate) Order.

9.5. Telecoms

Cable and Wireless, a major international telecommunications company, was privatised in 1981. This happened through a fixed price offering of 49.4% of its shares in 1981, a tender offer of an additional 22.3% in 1983 and a further fixed price offer of 22.7% in 1985.

MMC (1989) investigated the the proposed acquisition of The Plessey Company plc by a company jointly owned by The General Electric Company. plc (GEC) and Siemens AG. The MMC allowed the merger but found adverse effects in the form of a reduction of competition. The MMC recommended that GEC not be allowed to acquire control of some parts of Plessey's activities which should pass to Siemens only.

GEC and Siemens undertook[41] a) that GEC would not acquire any control over Plessey's radar and military communications business and traffic control activities; b) that arrangements for the ownership and management of Plessey's defence, R&D, and semiconductor businesses would be made to comply with national security requirements; c) that access to technologoy and licences for production of JTDIS equipment would be available to any competitor nominated by the Ministry of Defence.

9.6. Textiles

MMC (1989) investigated two merger situations involving Coats Viyella plc (Coats) and the Tootal Group Plc (Tootal). The first involved Coat's further acquisition of Tootal equity which raised its holding to 29.9 per cent, the second involved an offer for all Tootal's issued share capital. The impact of these proposed mergers was found to have adverse effects through: a) reduction in competition; b) higher prices; c) reduced consumer choice. The merger was allowed but Coats undertook[42] to dispose of its interest in the UK supply of domestic sewing thread and in Gutermann & Co. Until these disposals Coats undertook to exercise no more

[41] ORDERS SI 1989 : 27 The Merger Reference (GEC, Siemens and Plessey) Order.

[42] ORDERS SI 1989 : 1054 The Merger Reference (Coats Viyella PLC and Tootal Group PLC) Order.

than 9.9 percent of its voting rights in Tootal.

9.7. Razors

MMC (1991a,b) relate to concurrent references to the Commission concerning the situation arising from a leveraged buy-out of the Consumer Products (CP) division of Stora, which included the Wilkinson Sword business, using a shelf company to be called Swedish Match. Finance for the transaction was to be provided by a number of Swedish investor institutions together with the Gillette company and its subsidiaries. The reports concluded that a monopoly situation existed in favour of Gillette UK and that the affect of Gillette's involvement in the transaction, specifically the giving of assistance to and the provision of finance for Swedish Match in connection with a buy-out, was to weaken the competitiveness of its main competitor in the United Kingdom, to strengthen its competitive position, and to reduce competition. This would result in prices being higher than they would otherwise be and a reduction in consumer choice. The reports recommended that Gillette UK should dispose of its equity interests.[43]

9.8. Steel

British Steel, the largest UK steel producer, was privatised in 1987 through a fixed price offer of 100% of its shares.

9.9. Ordnance

Royal Ordnance, manufacturer of artillery, ammunition, explosives, ordnance, small arms and rocket motors, sold to British Aerospace in 1987.

[43] ORDERS SI 1991 : 750 The Merger Situation (Stora/Swedish Match/Gillette) (Interim Provision) Order SI 1993 : 1703 The Merger Situation (Stora/Swedish Match/Gillette) (Interim Provision) (Revocation) Order.

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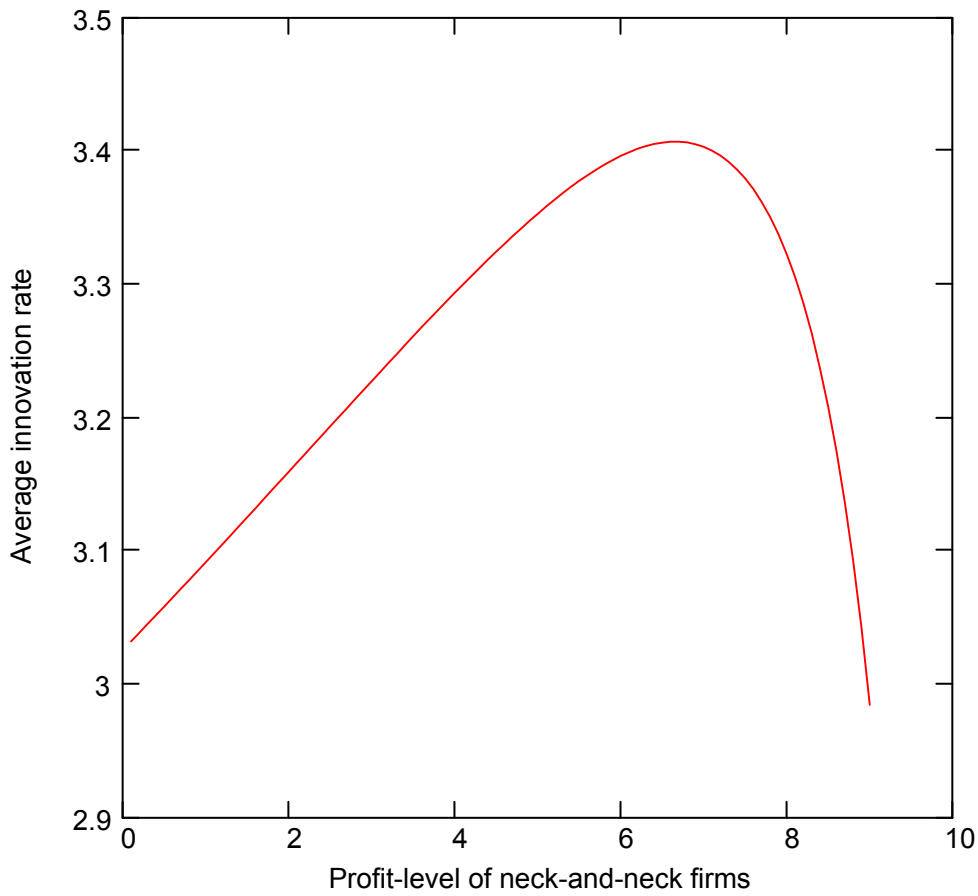


As competition decreases, the equilibrium profit level π_0 of neck-and-neck firms increases, resulting eventually in a fall in the economy-wide rate of growth.

Figure 1

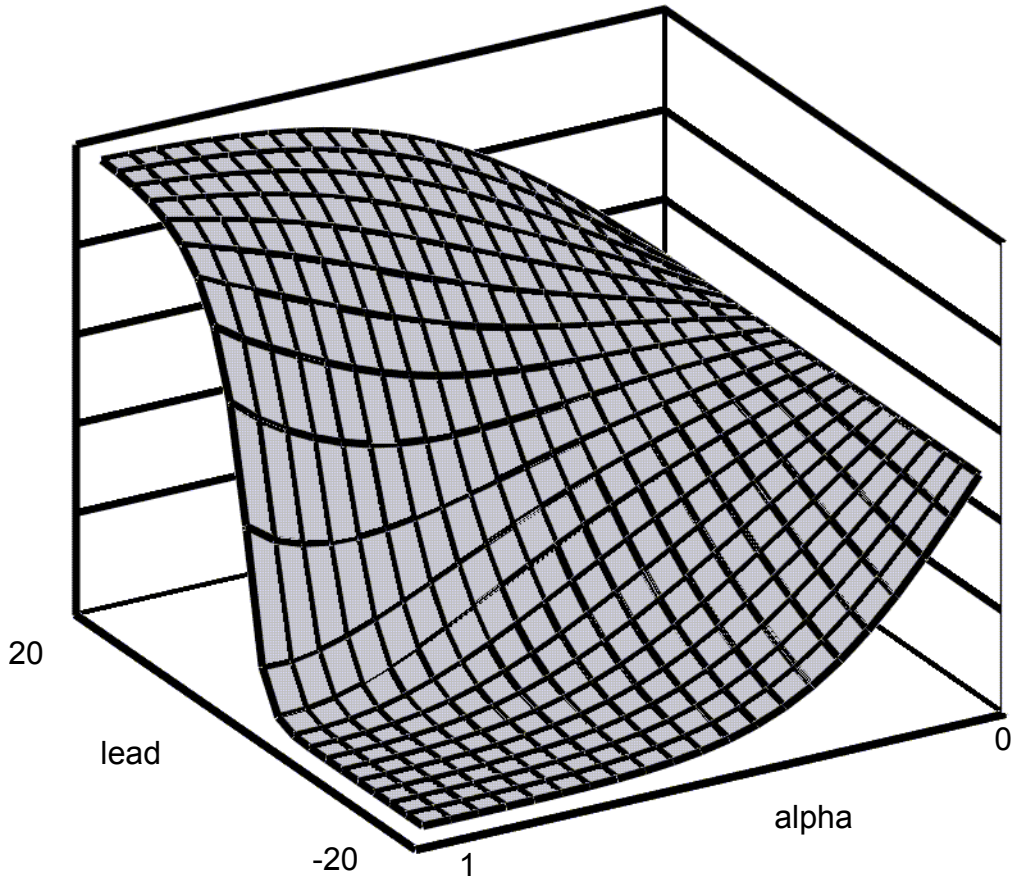


Figure 2: How a firm's value depends on its technogical lead and on the degree of product market competition

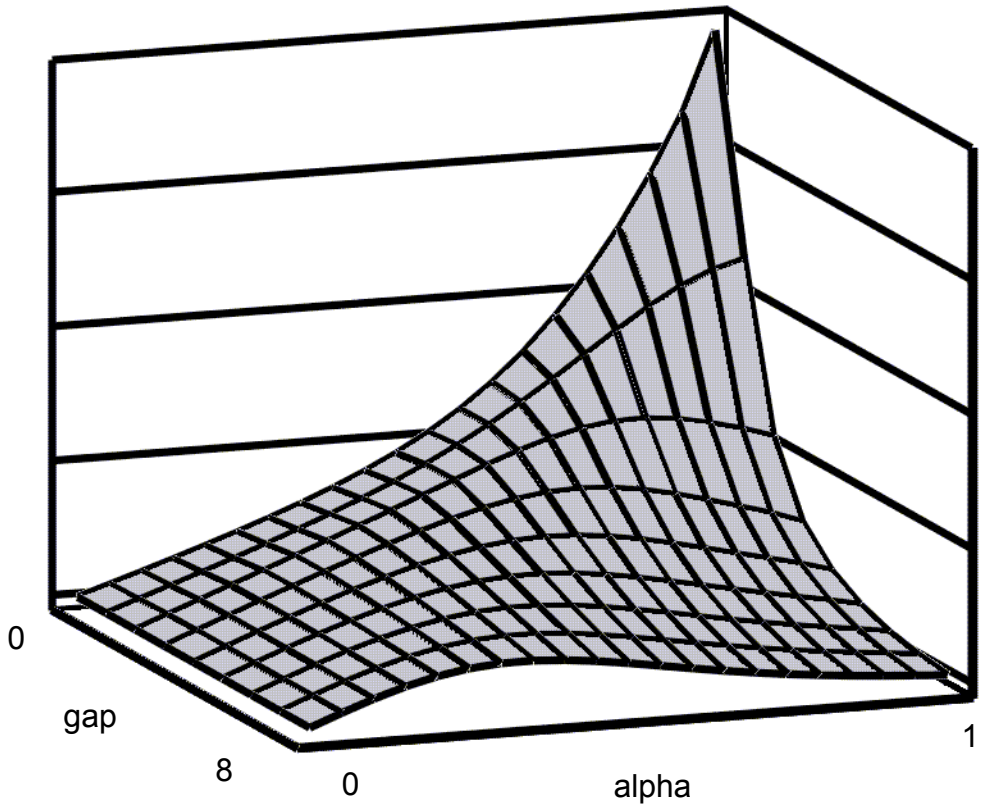


Figure 3: Total Industry R&D as a function of the technological gap between leader and follower and of the degree of product market competition.

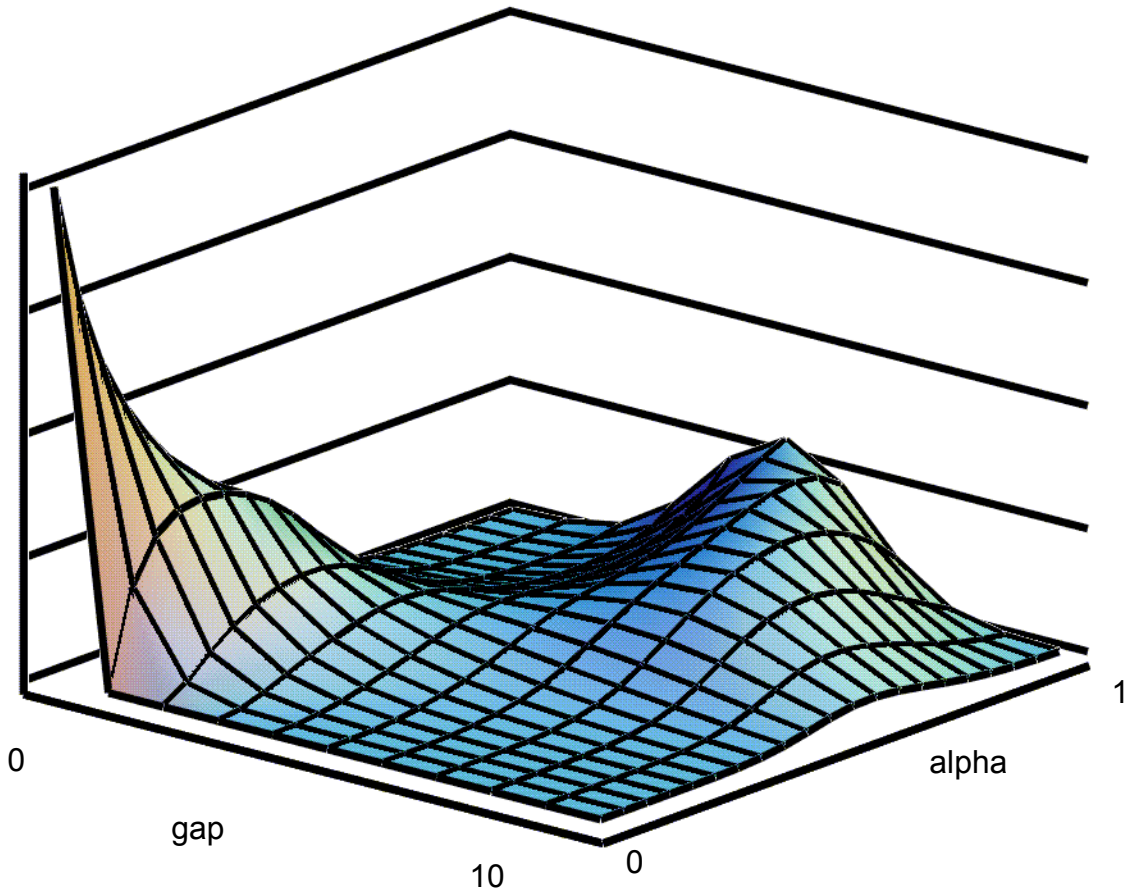


Figure 4: The cross-industry distribution of technological gaps for different degrees of product market competition

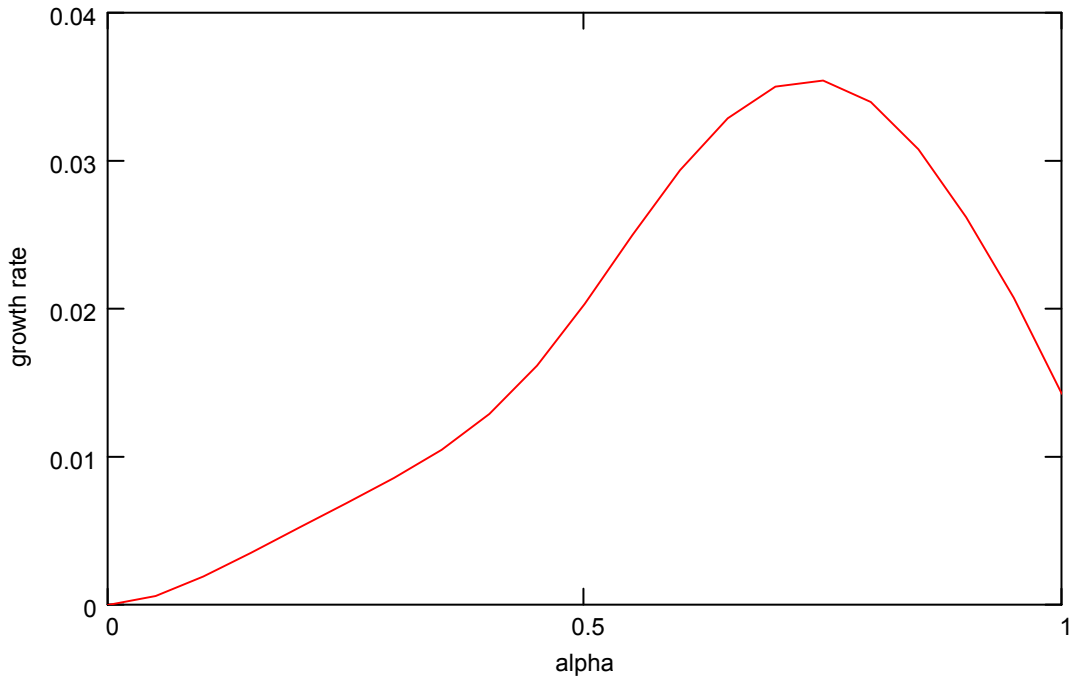


Figure 5: The effects of competition on growth

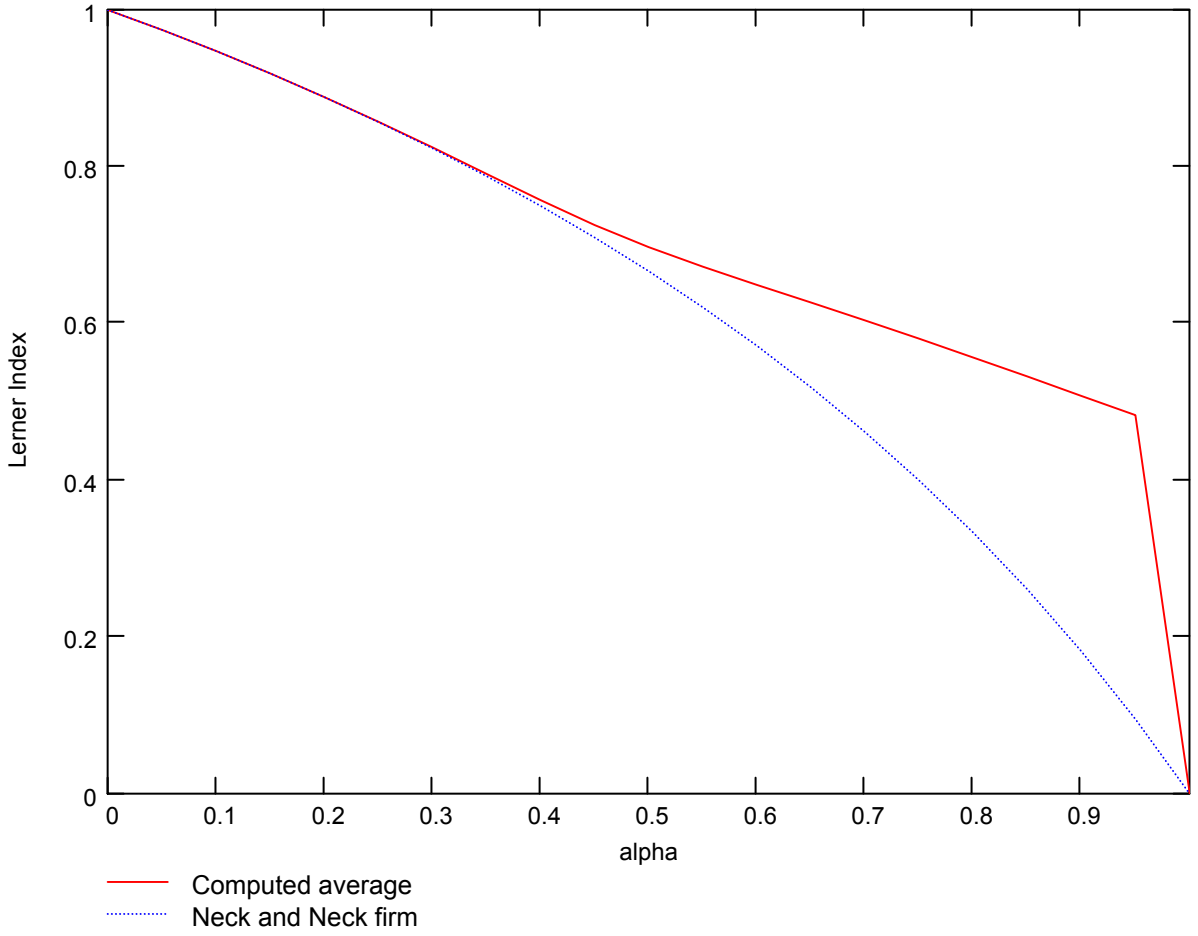
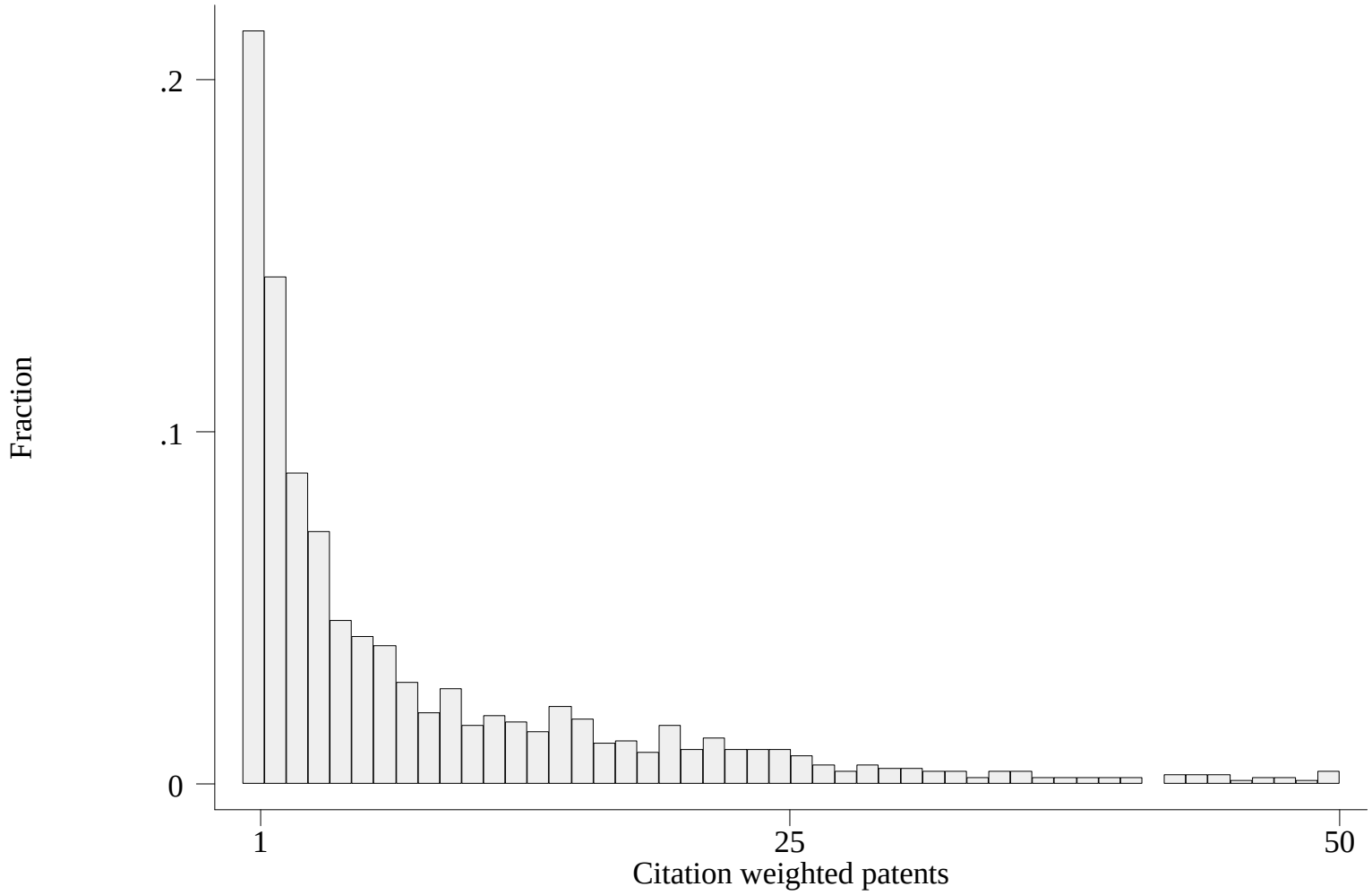


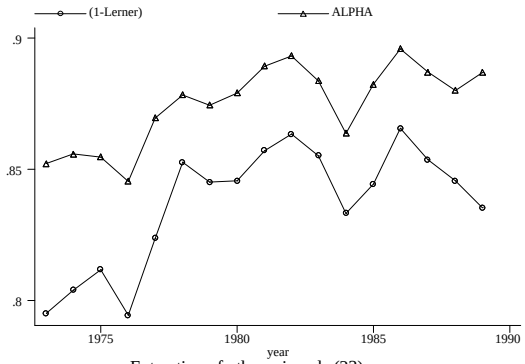
Figure A1: The theoretical relation between Alpha and Lerner

Figure 5.1: Distribution of Patents (0 < p < 50)

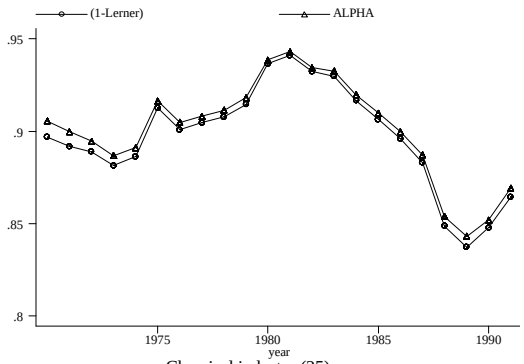


Notes: Excluding zeros (37%) and counts over 50 per year.

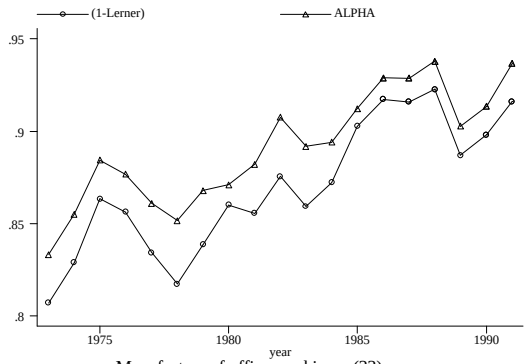
Figure 5.2: Alpha compared to 1-Lerner



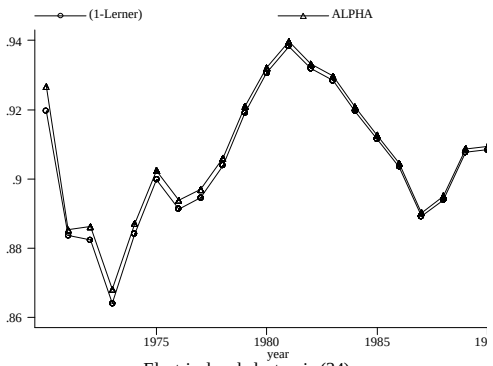
Extraction of other minerals (23)



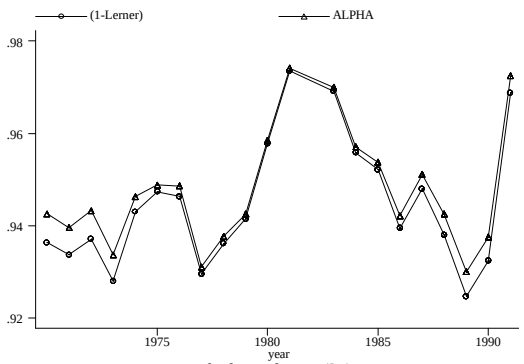
Chemical industry (25)



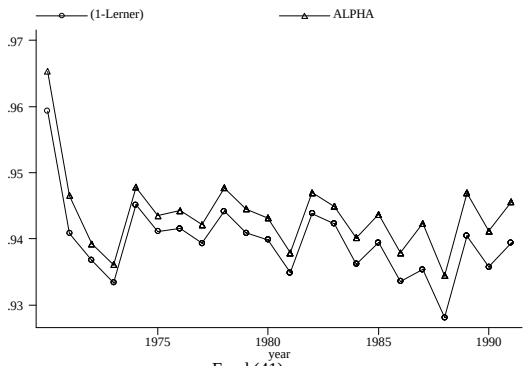
Manufacture of office machinery (33)



Electrical and electronic (34)



Motor vehicles and parts (35)



Food (41)

Figure 6.1a: Quadratic and spline with no controls

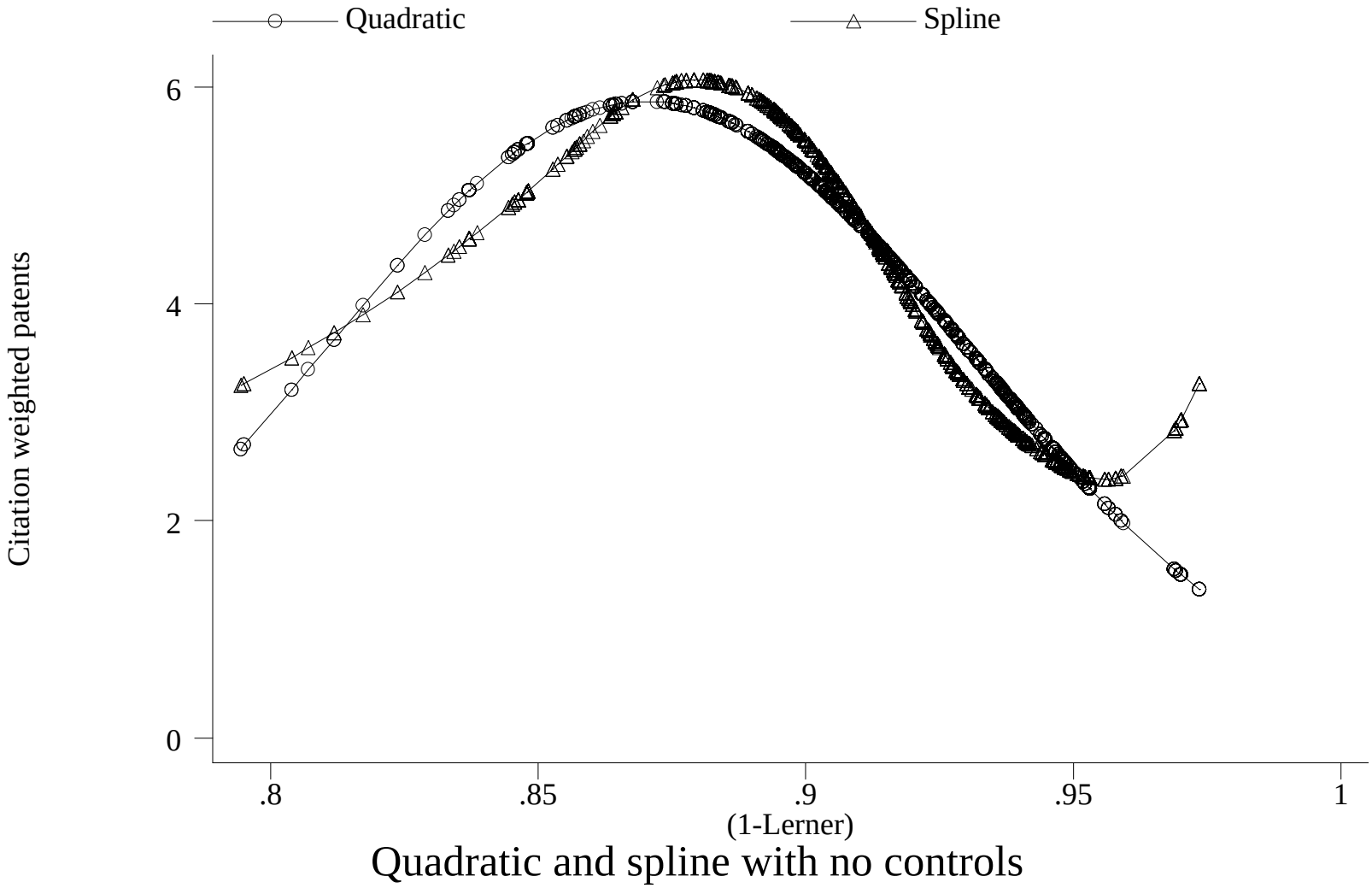
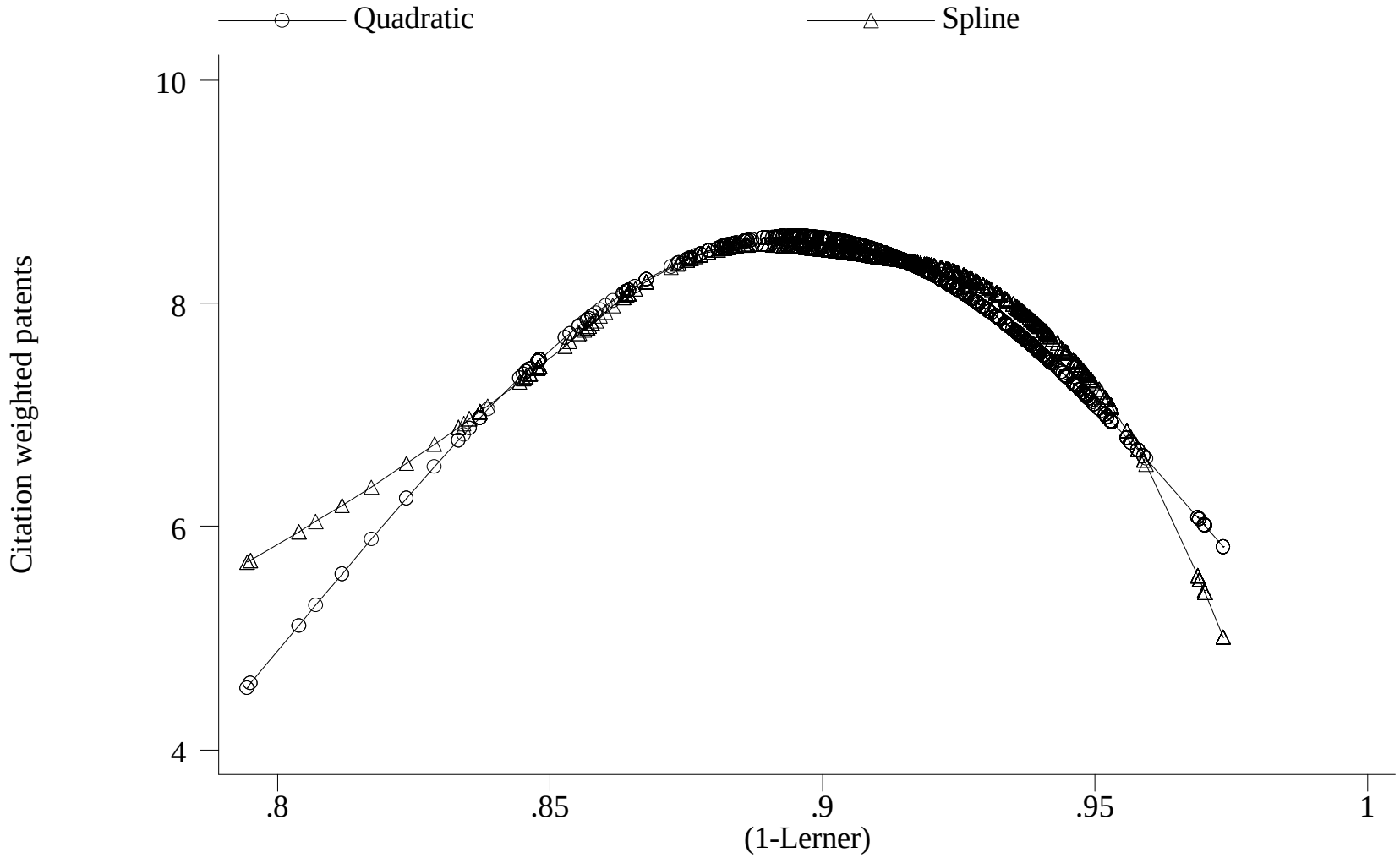


Figure 6.1b: Quadratic and spline with year and industry effects



Quadratic and spline with year and industry effects

Figure 6.1c: Four highest patenting industries

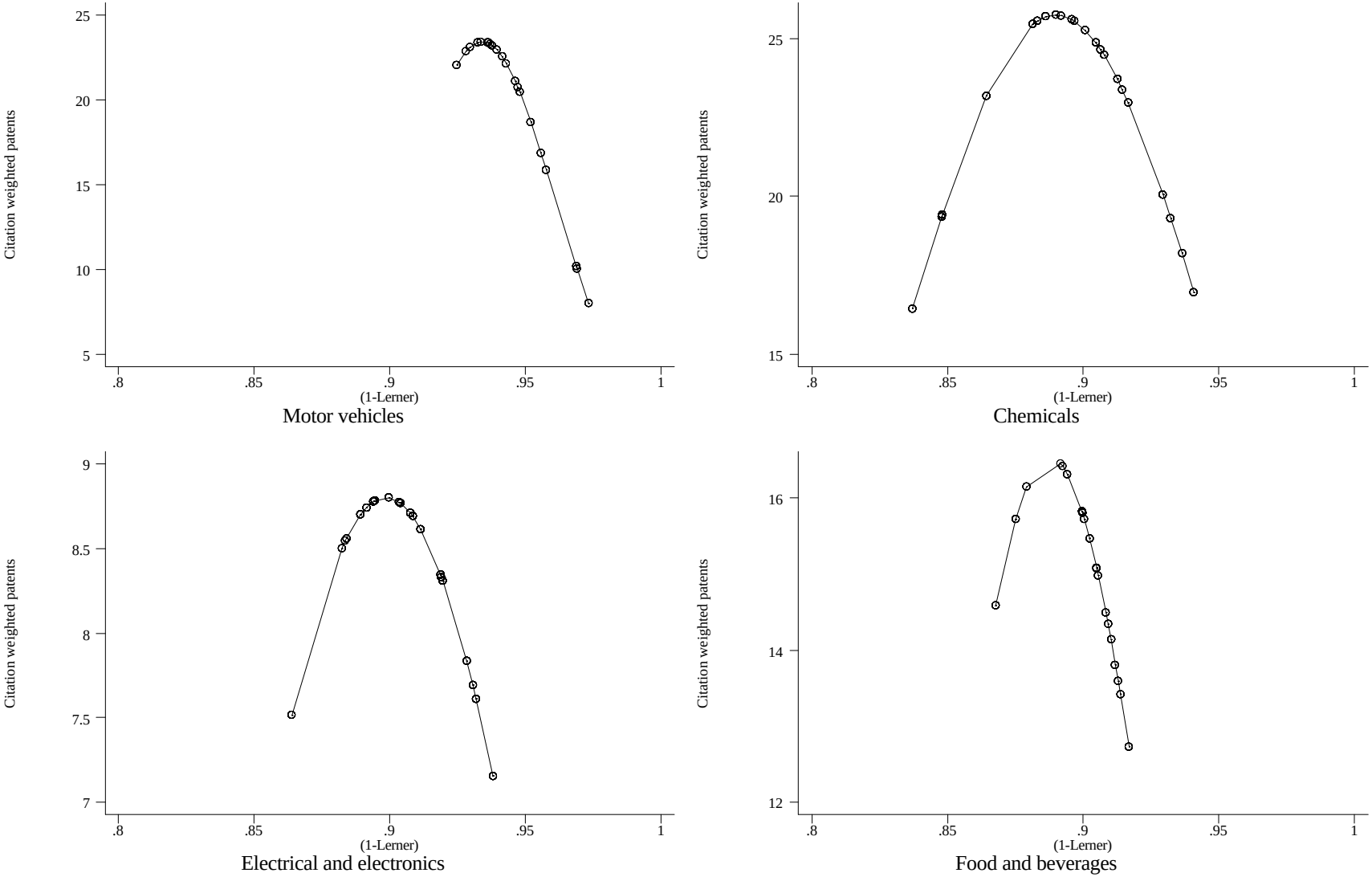
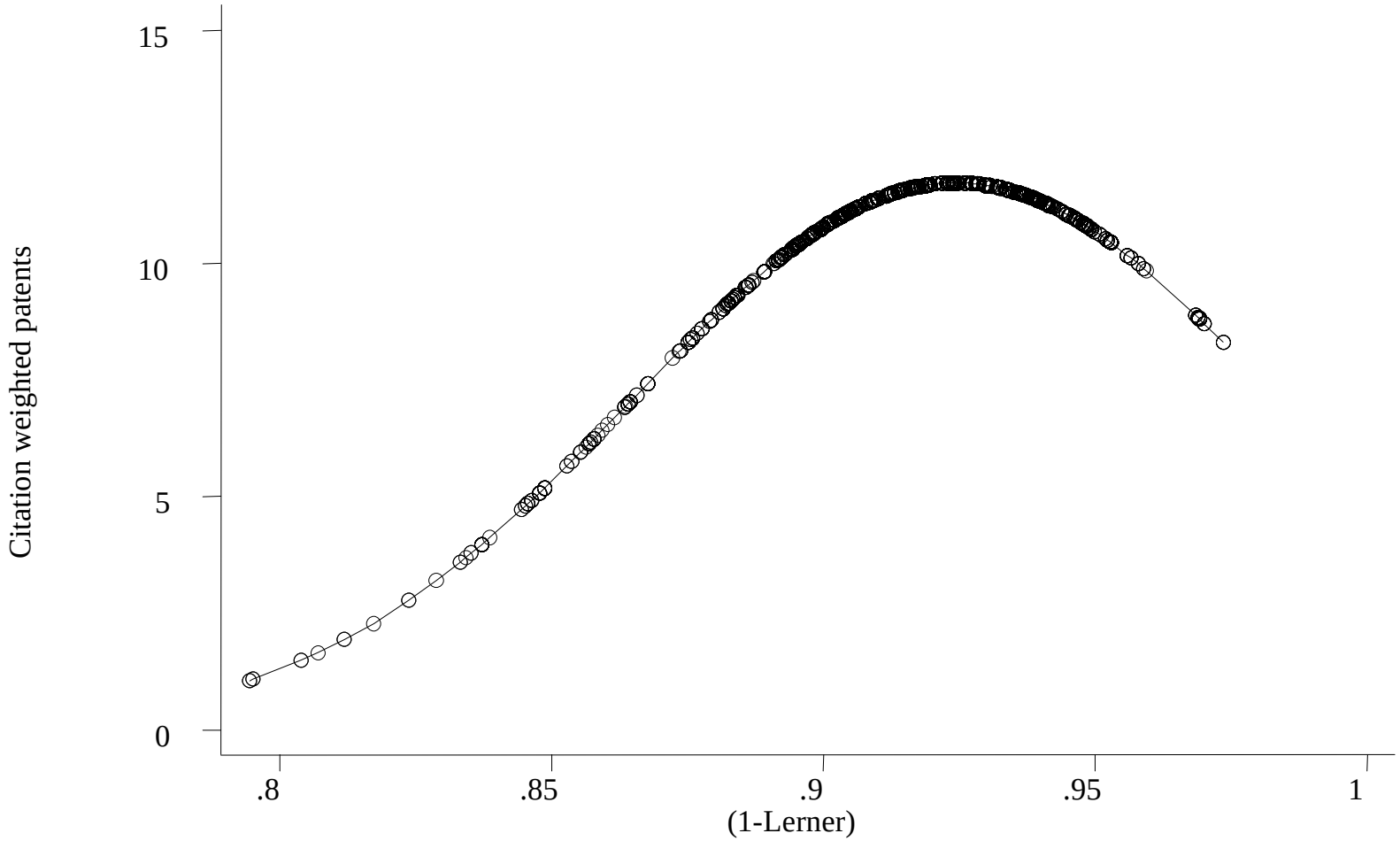


Figure 6.2a: Conditioning on firm level capital stock



Exponential Quadratic with firm capital, year and industry effects

Figure 6.2b: Quadratic with year and industry effects, with Lerner corrected for fixed costs

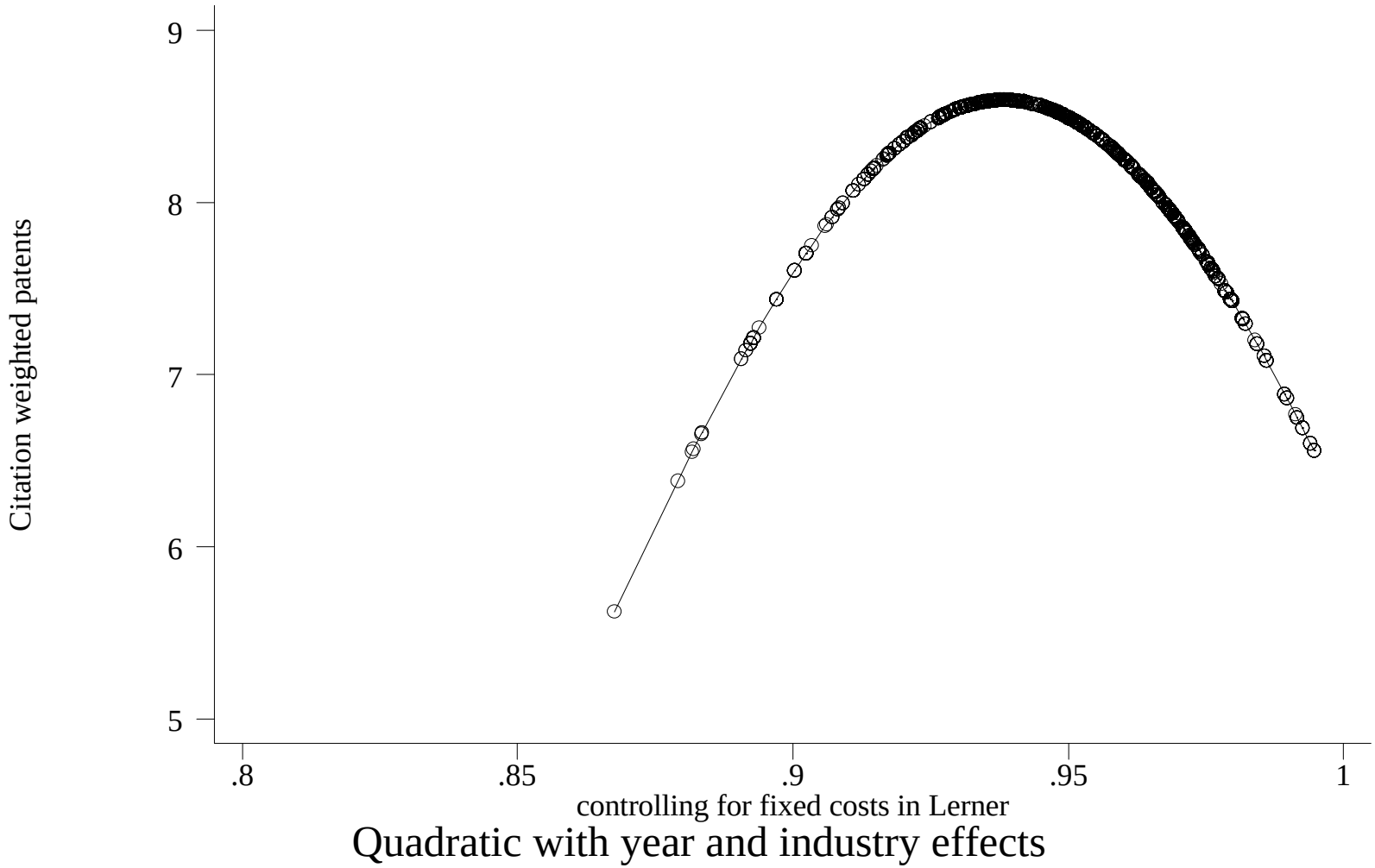
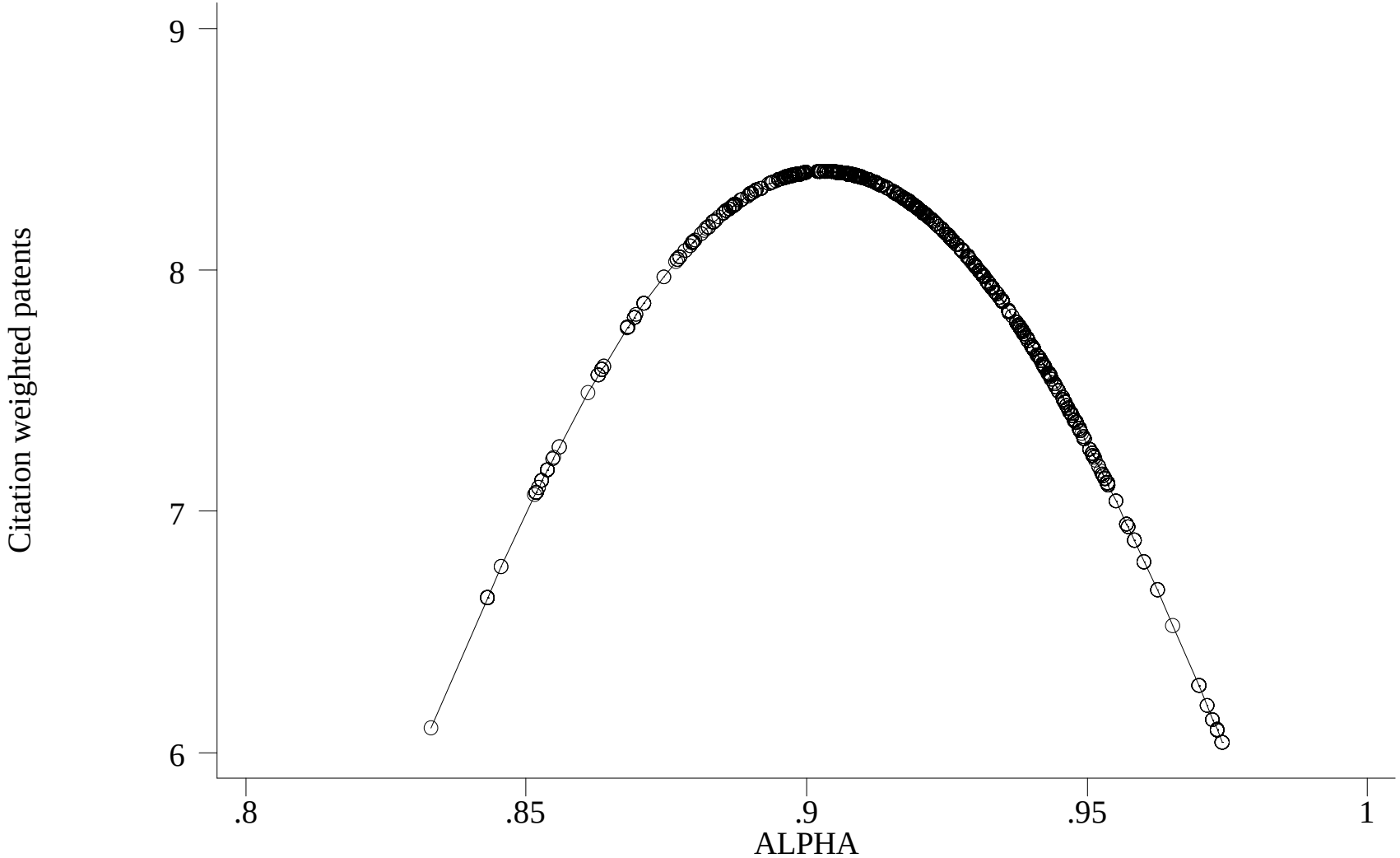
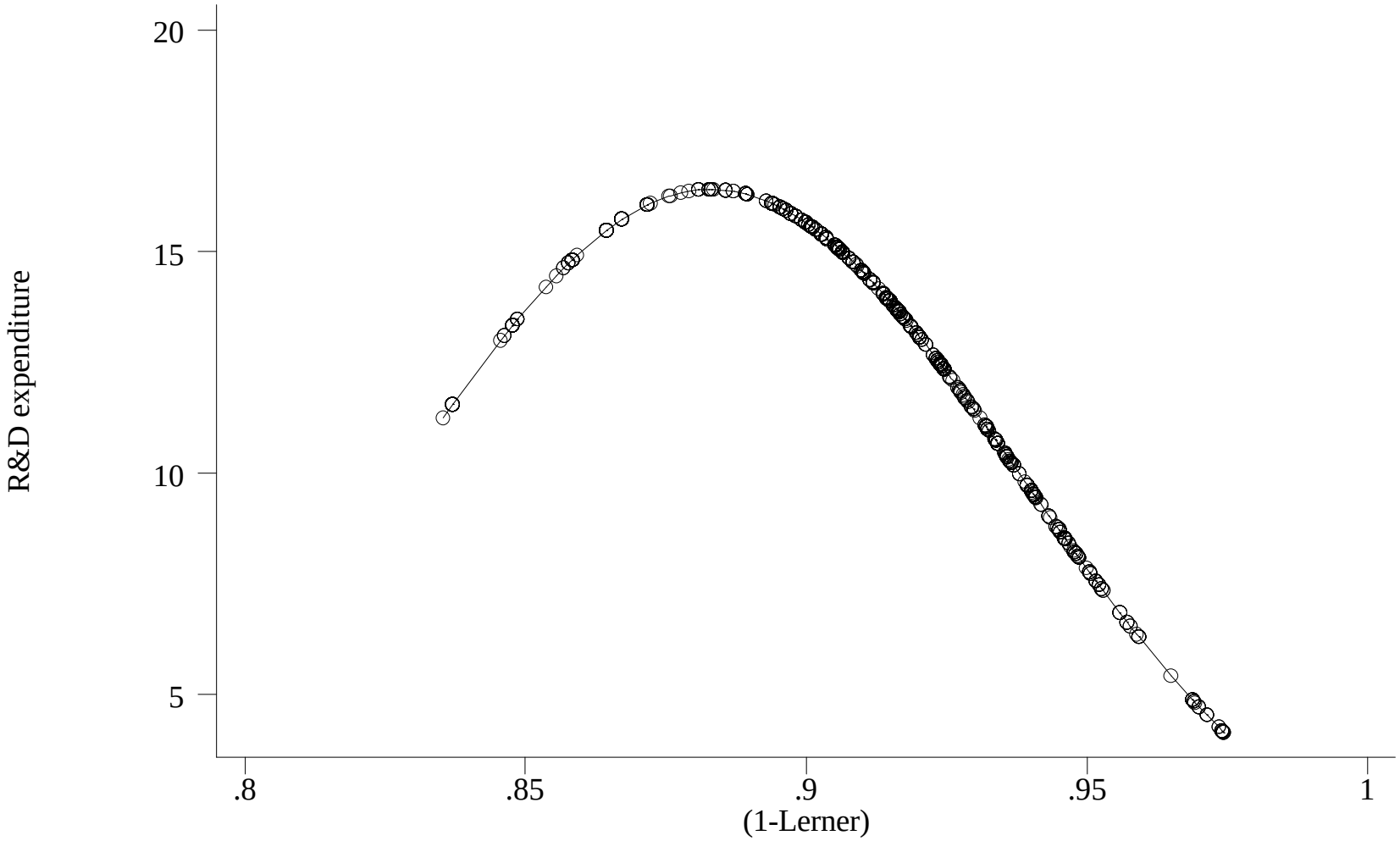


Figure 6.2c: Using alpha rather than 1-Lerner



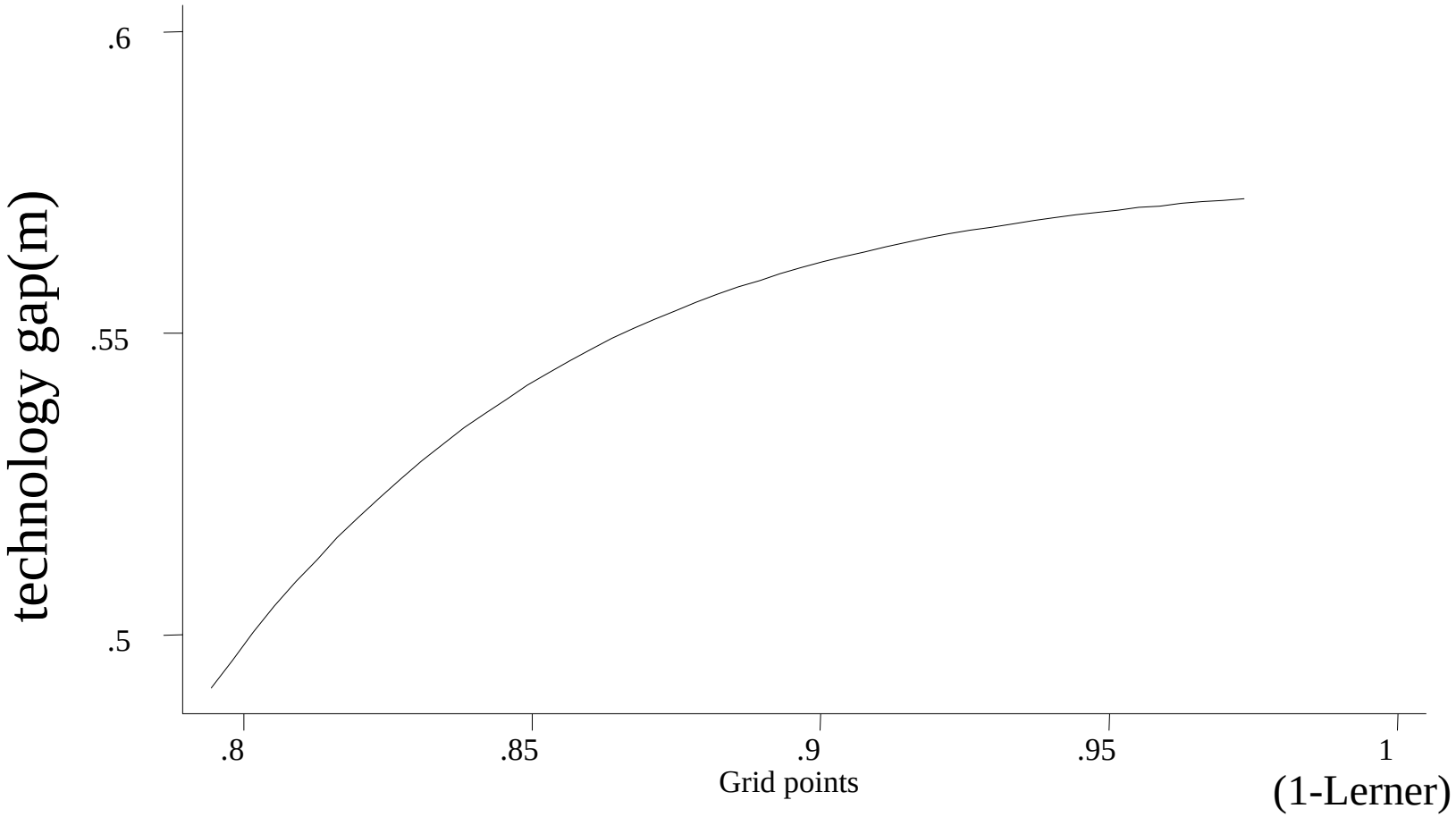
Quadratic with year and industry effects

Figure 6.2d: Using R&D instead of patents (1980-1994; main sample 1990-1994)



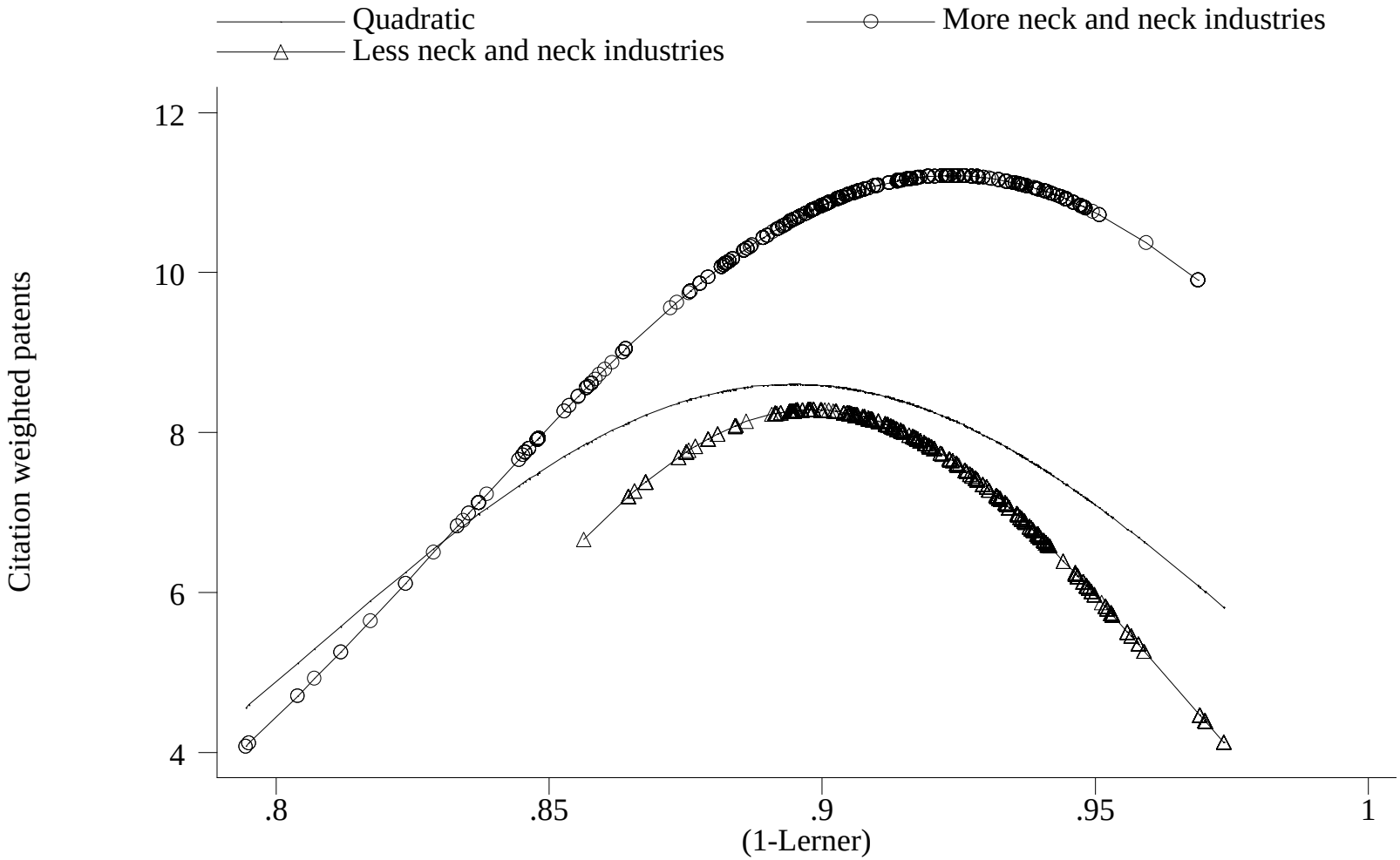
R&D with year and industry effects

Figure 6.3: Composition effect



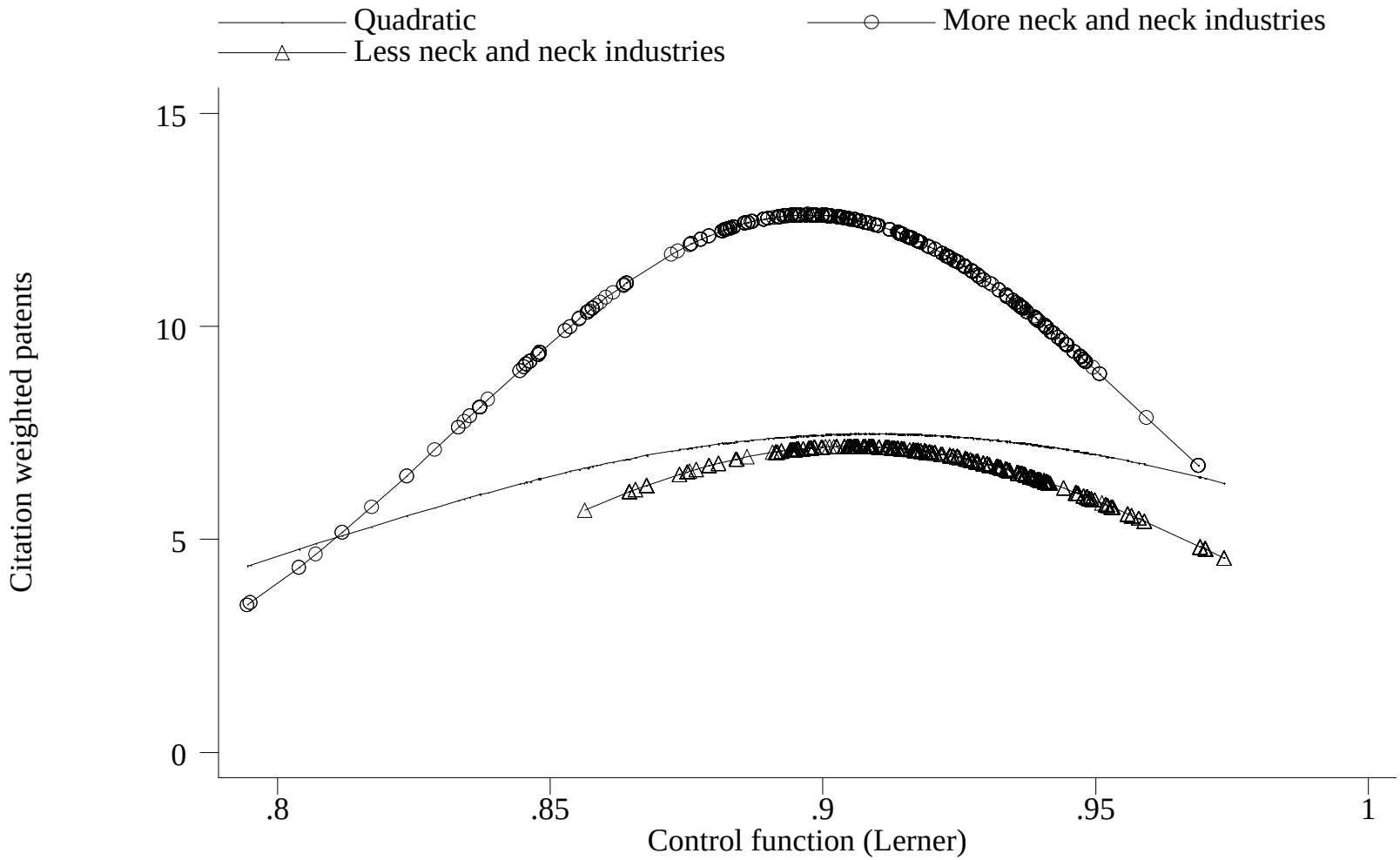
Notes: Kernel regression, bw = .05, k = 6

Figure 6.4: Neck and neck split (by TFP)



Neck and neck split with year and industry effects

Figure 6.5a: Neck and neck split, controlling for endogeneity of Lerner using control function



Neck and neck split with year and industry effects

Figure 6.5b: Neck and neck split, controlling for endogeneity of Lerner and split using control function

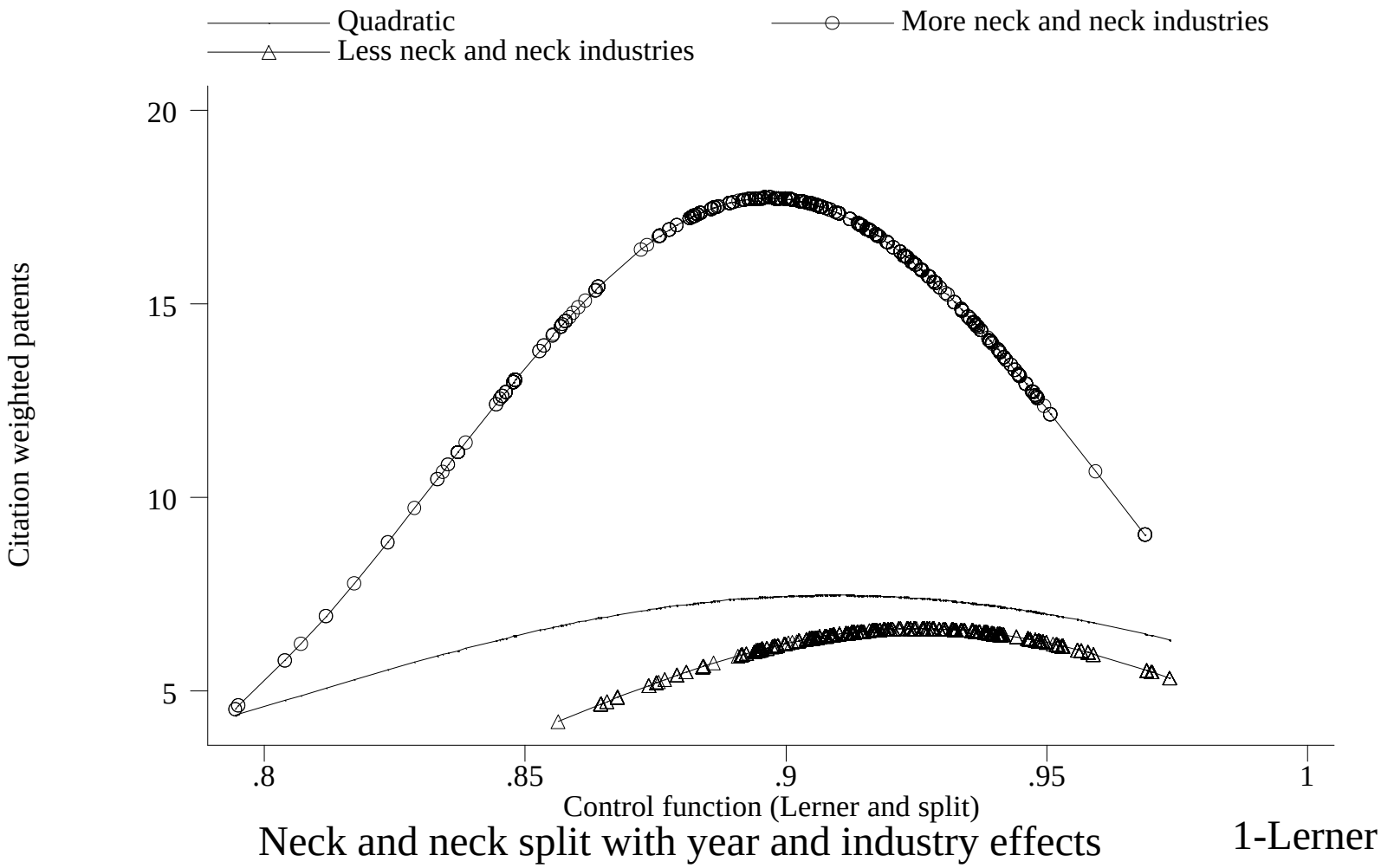


Figure 6.6a: Financial pressure split

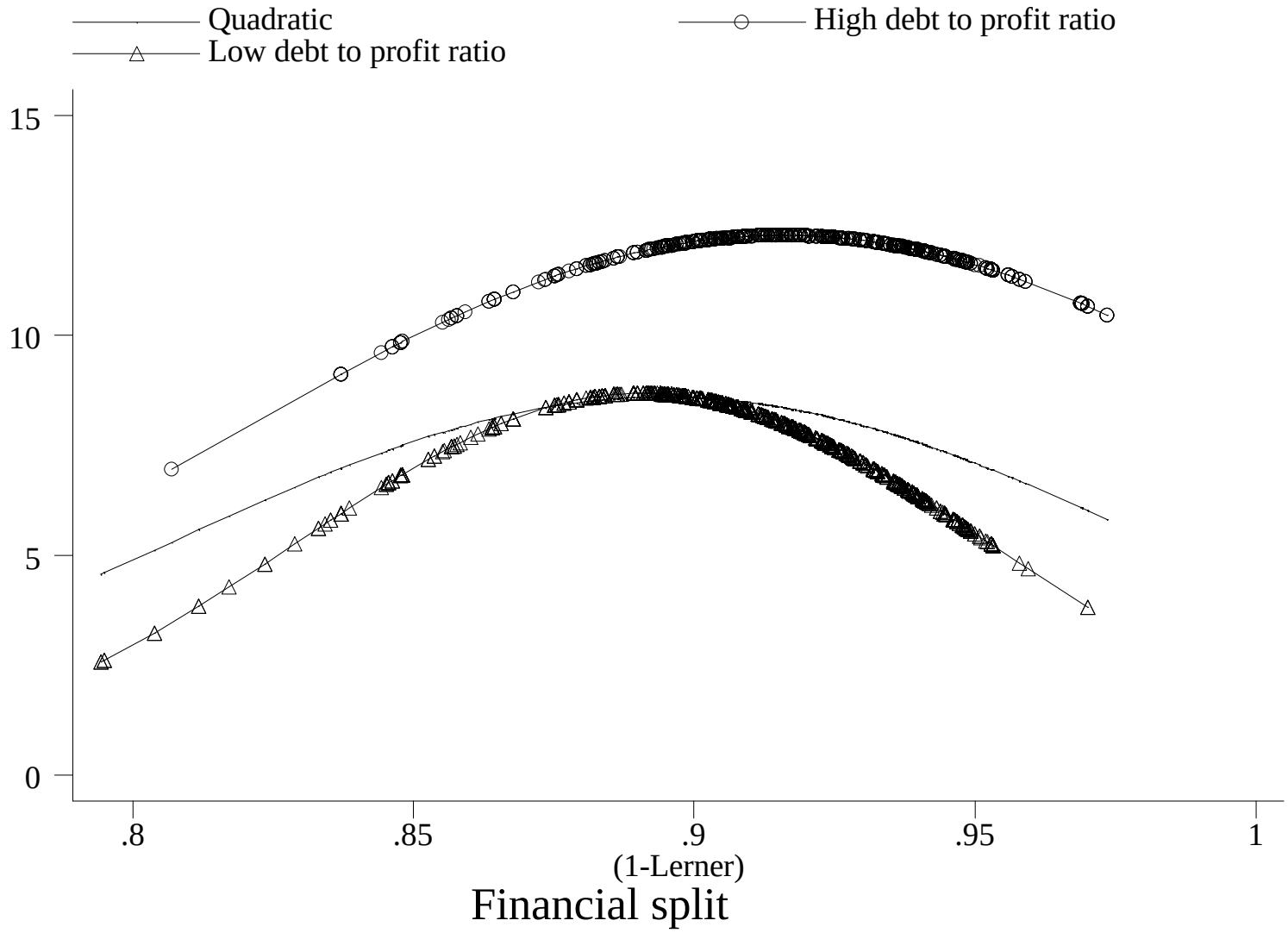


Figure 6.6b: Financial pressure split, controlling for endogeneity of Lerner using control function

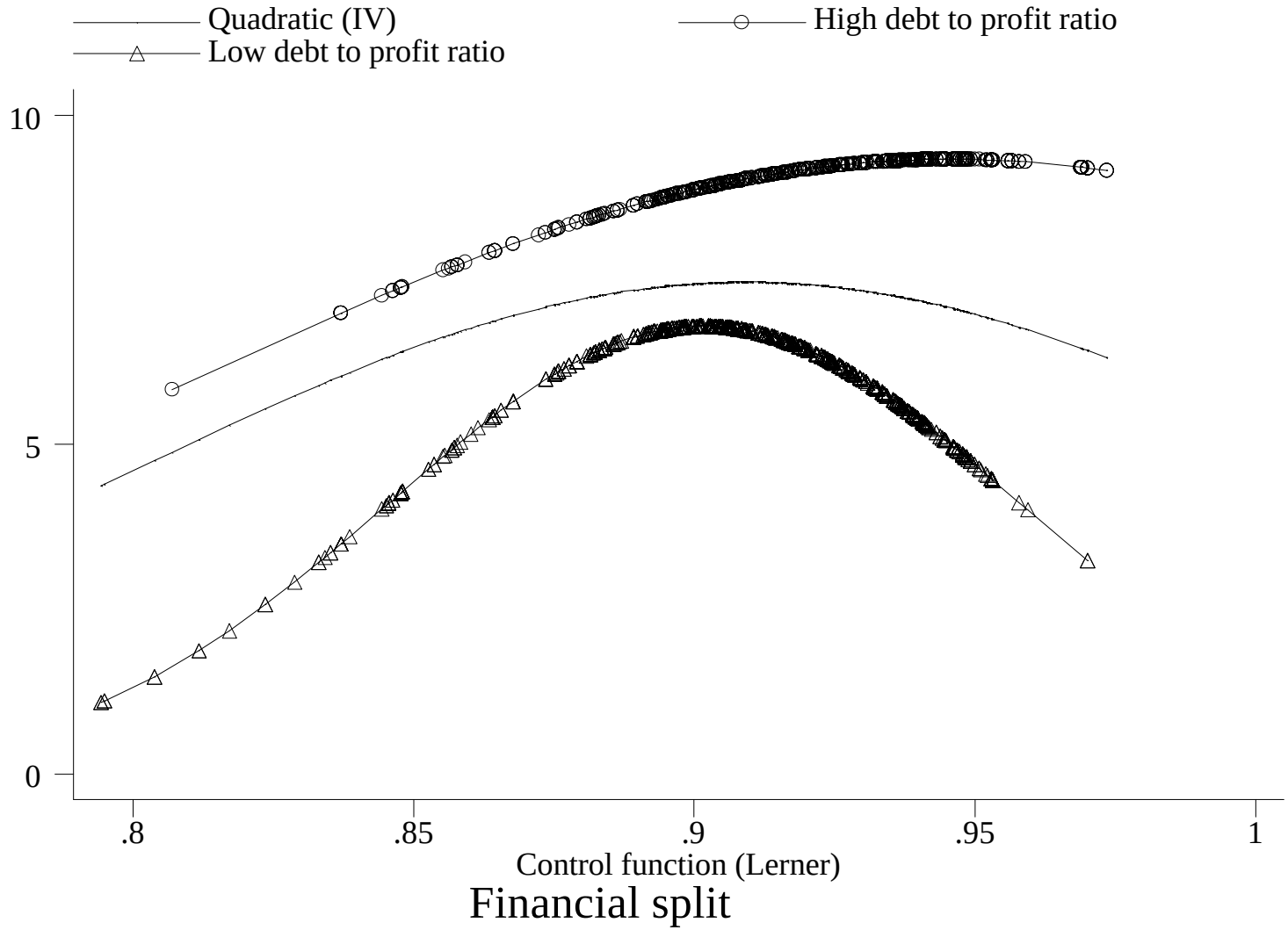
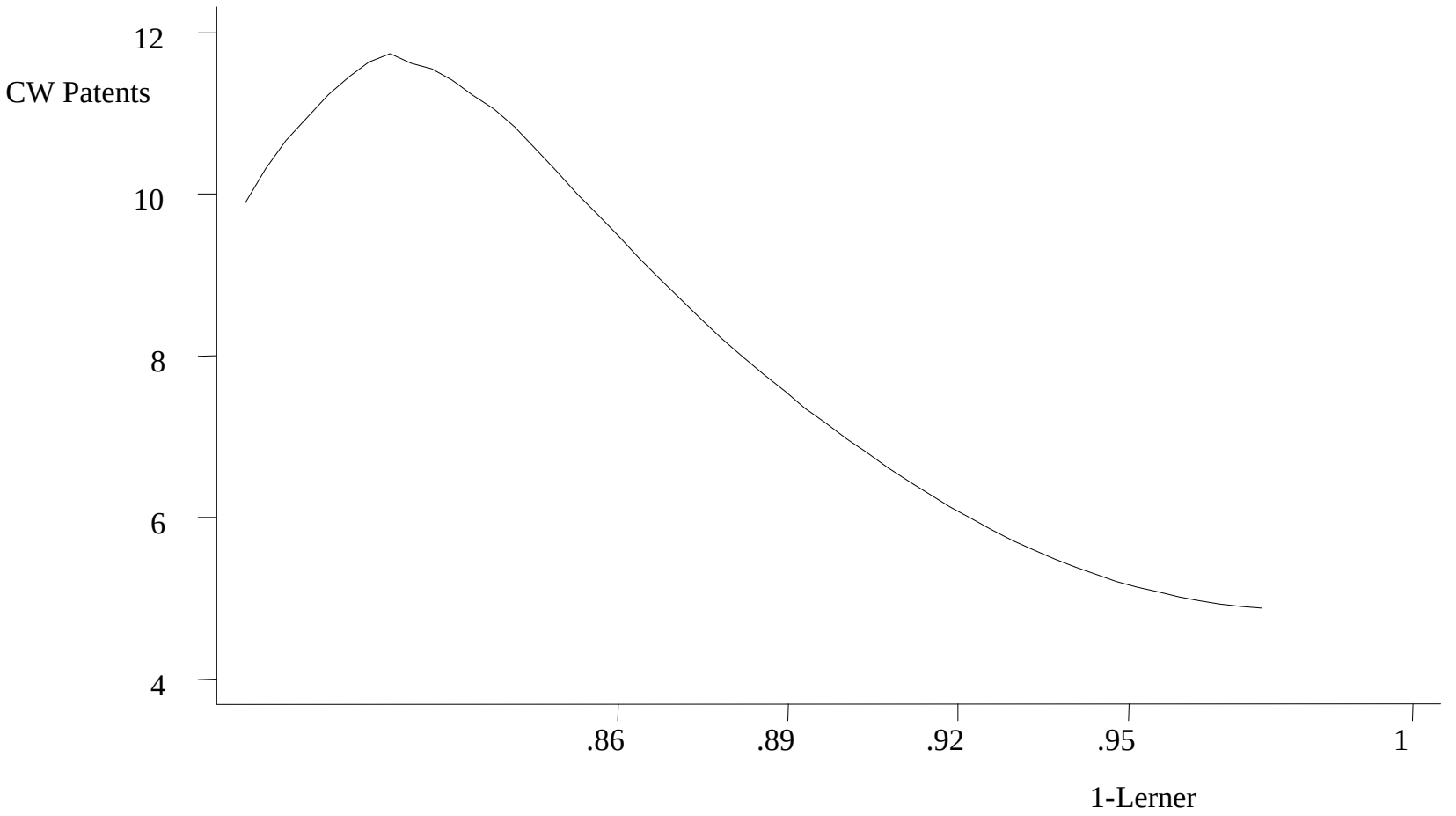


Figure A6.1a: Kernel Regression



Kernel regression, bw = .025, k = 6

Figure A6.1b: Quadratic and spline with no controls

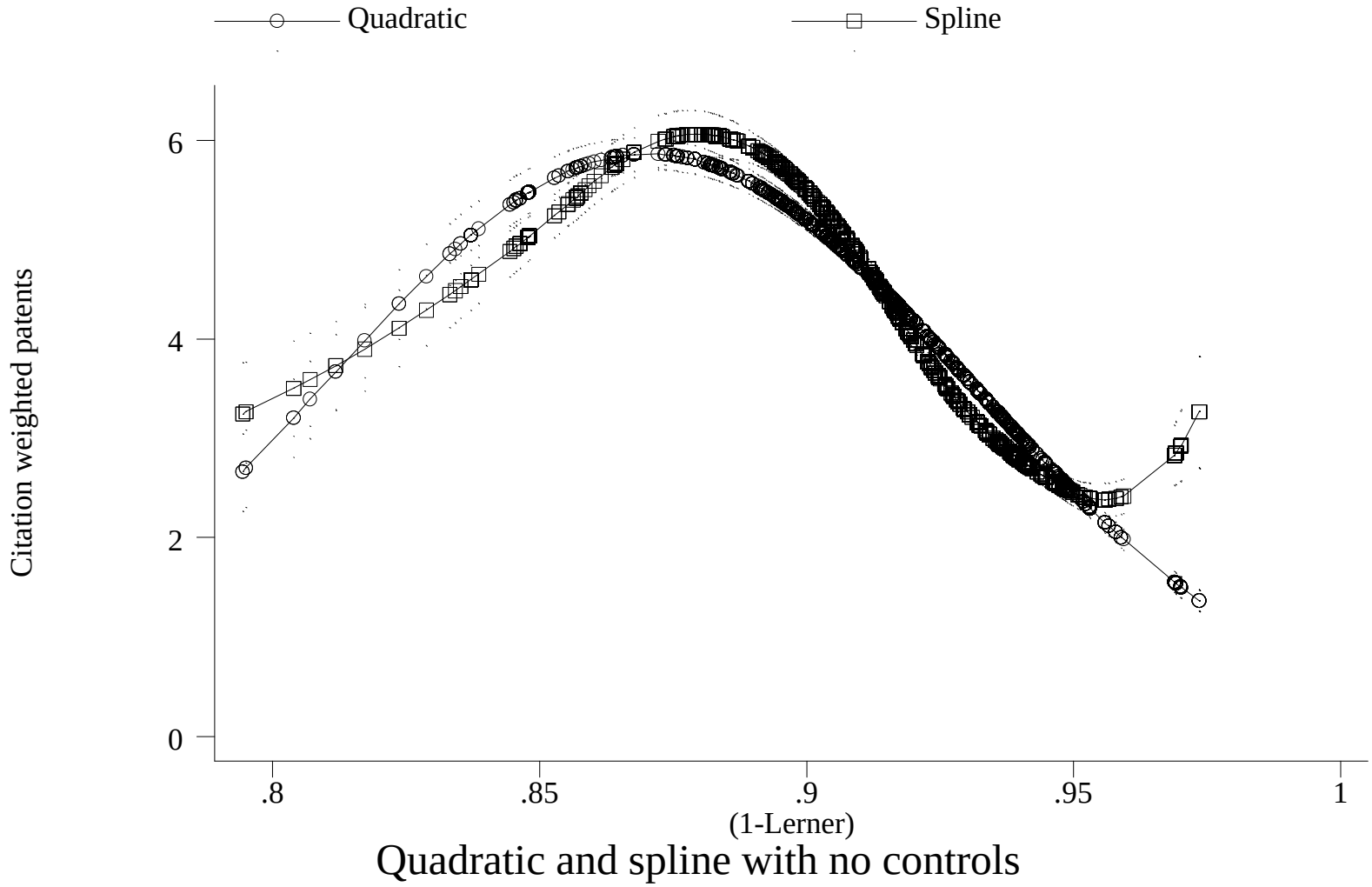
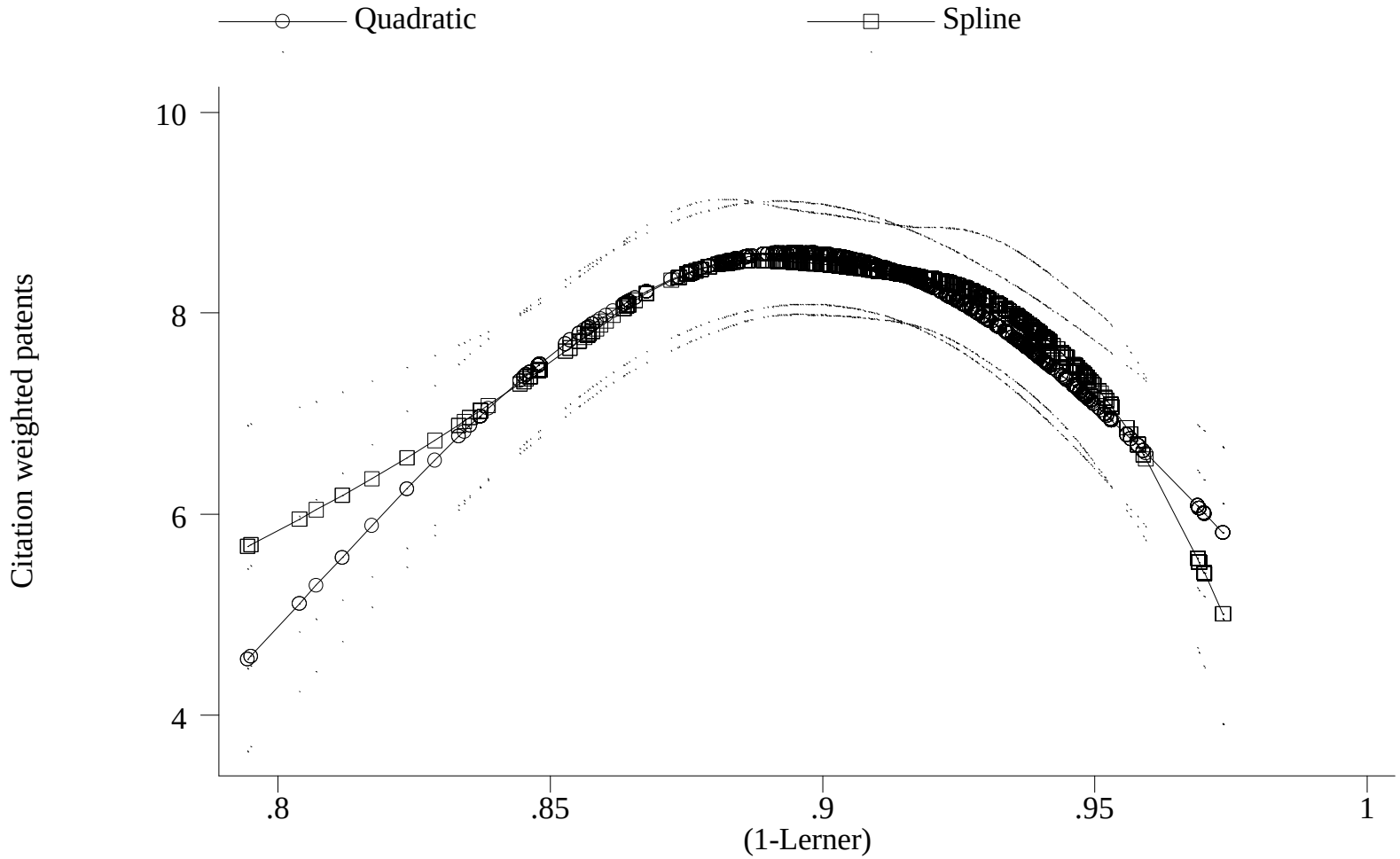


Figure A6.1c: Quadratic and spline with year and industry effects



Quadratic and spline with year and industry dummies

Figure A6.2: Balanced and unbalanced panel

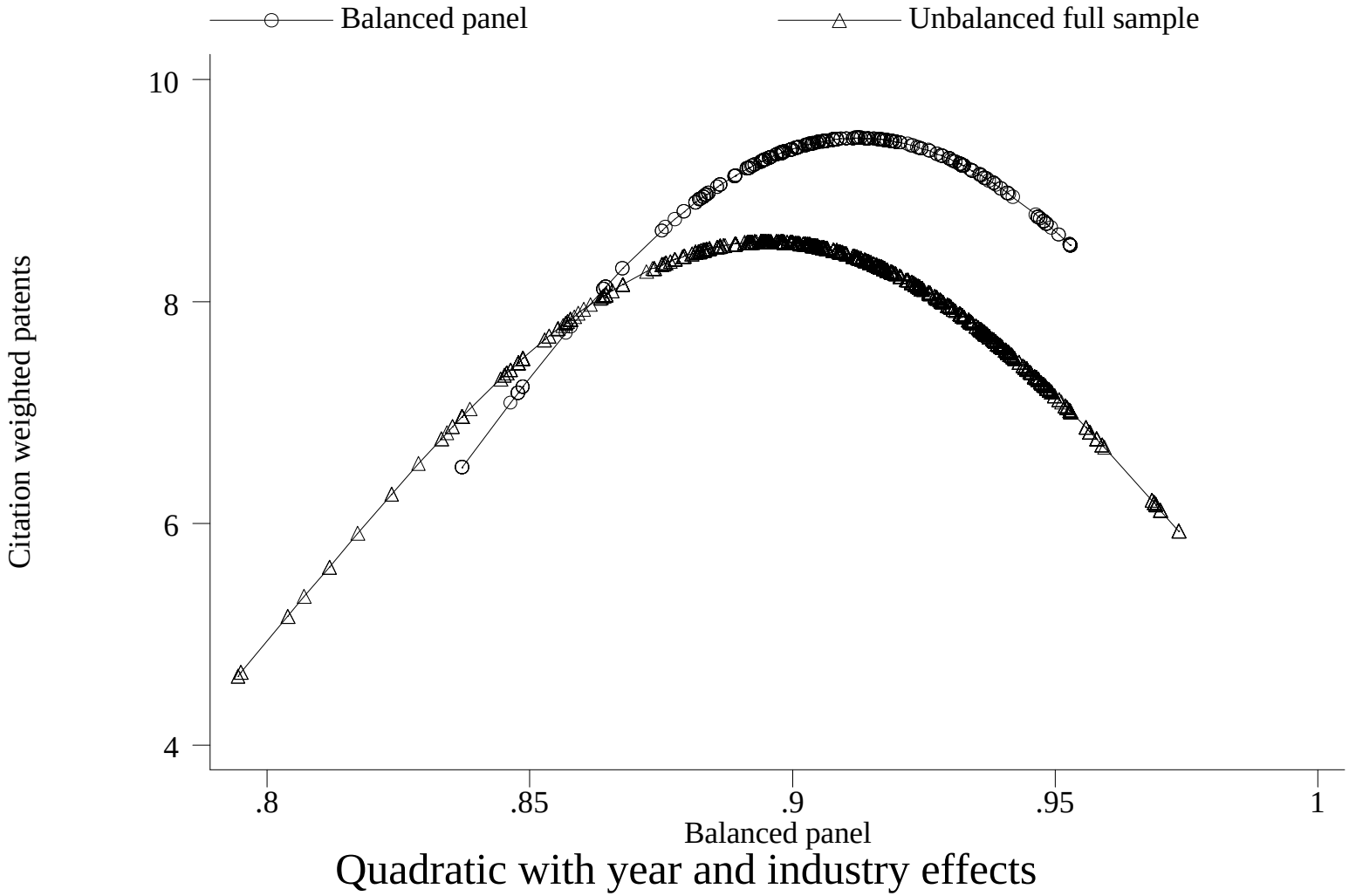


Figure A6.3a: Using initial Lerner on sum of patents

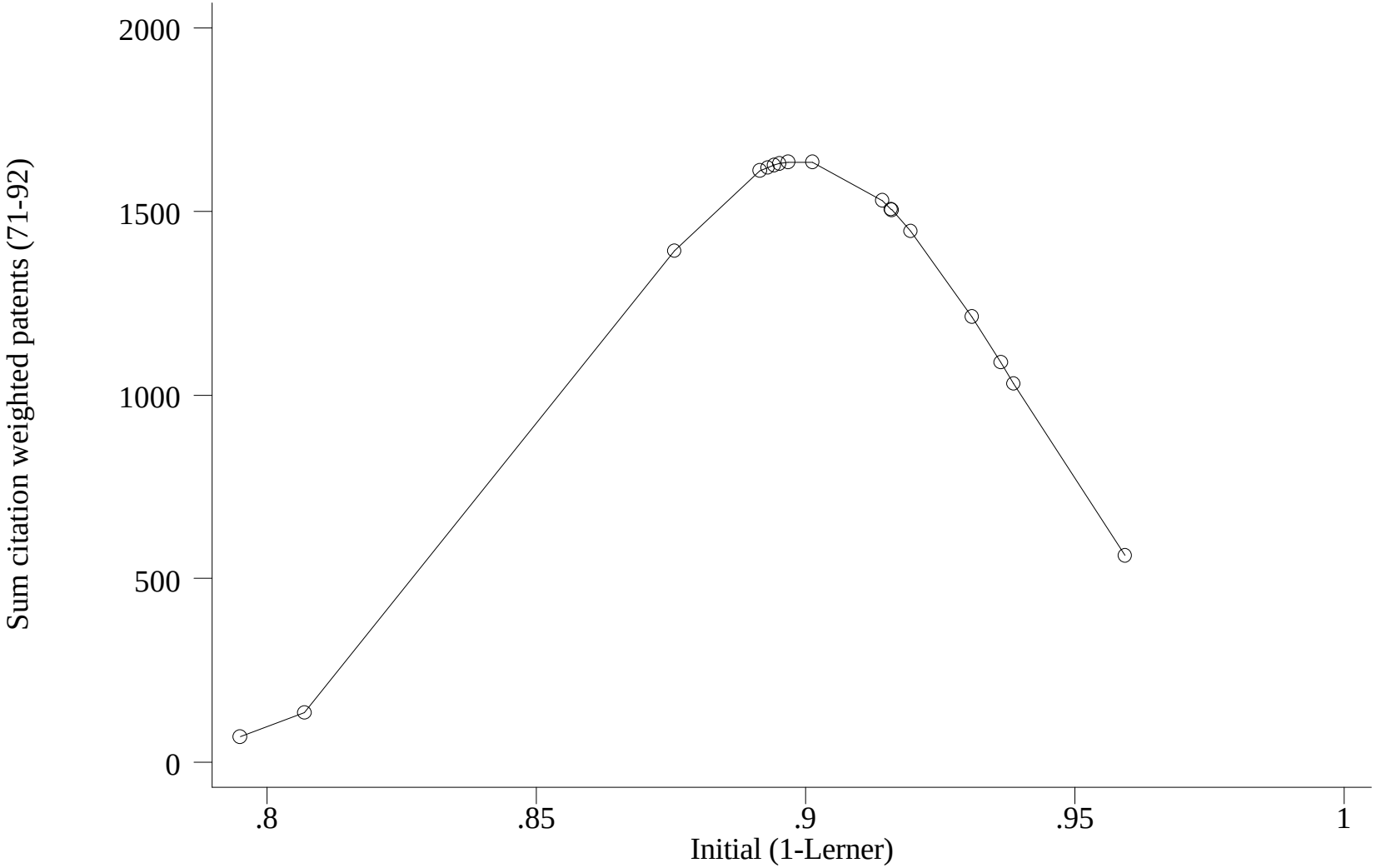


Figure A6.3b: Using lagged (once) Lerner

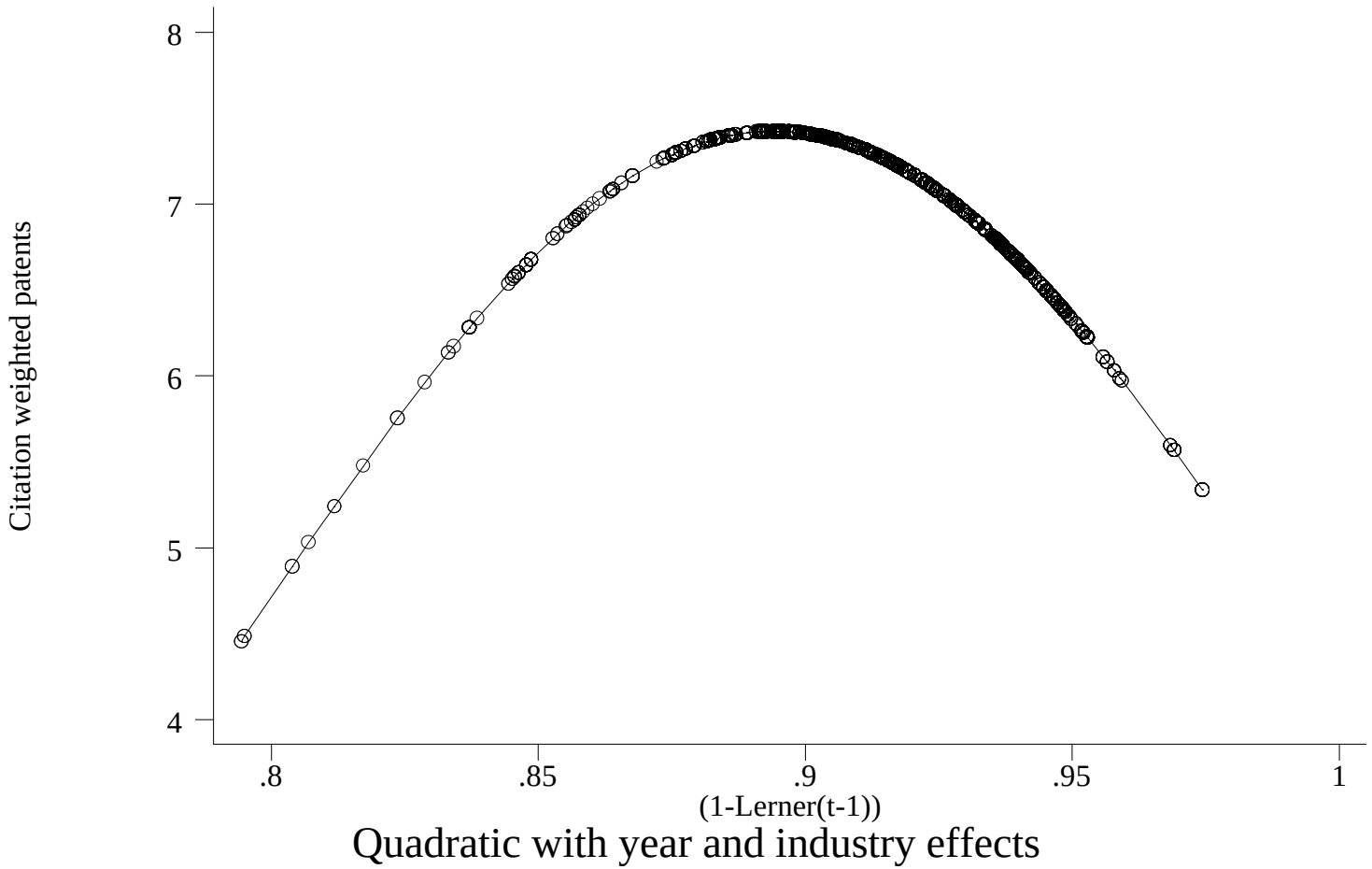


Figure A6.4: Neck and neck split (by TFP)

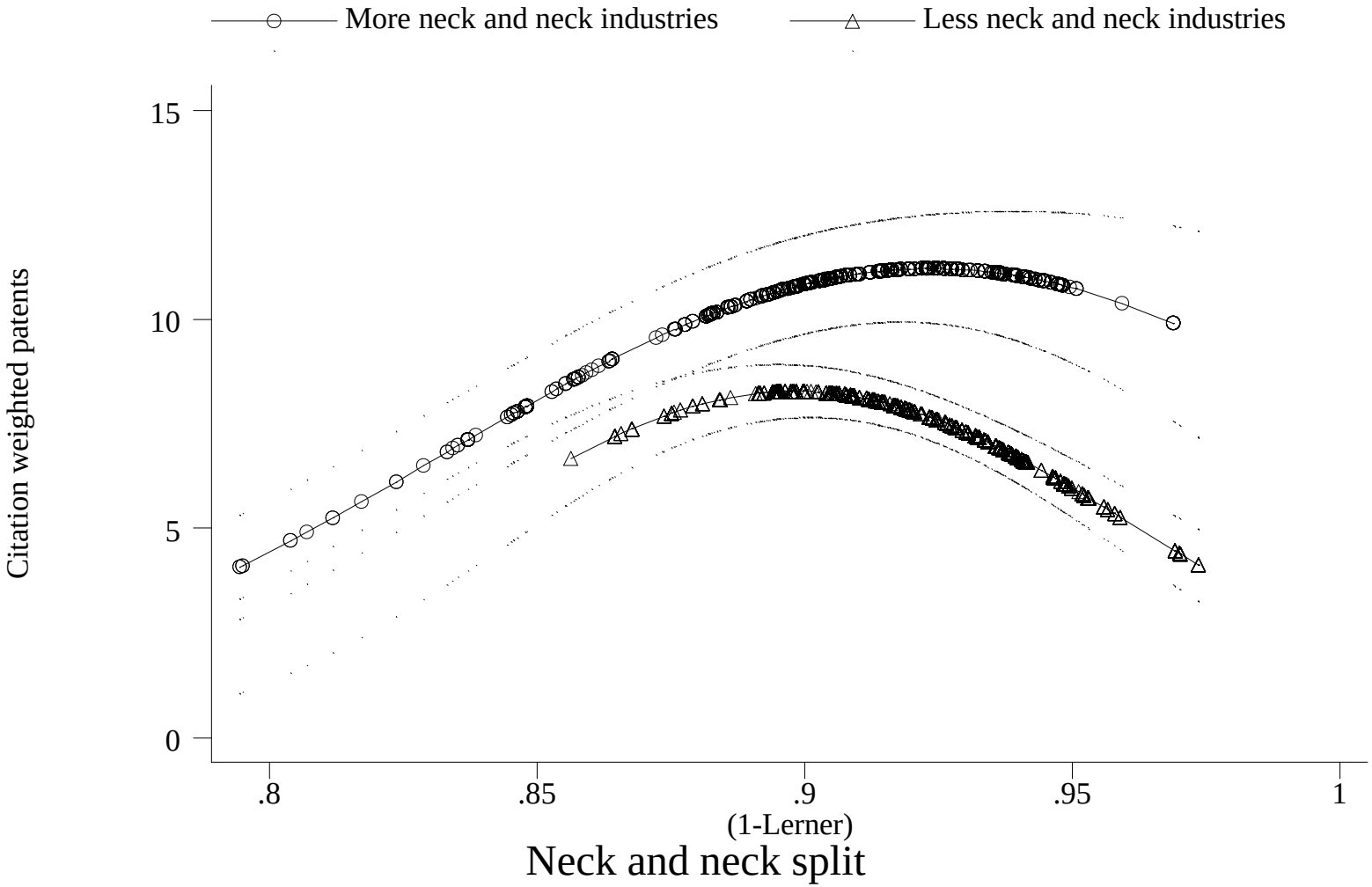


Figure A6.5a: Neck and neck split, controlling for endogeneity of Lerner using control function

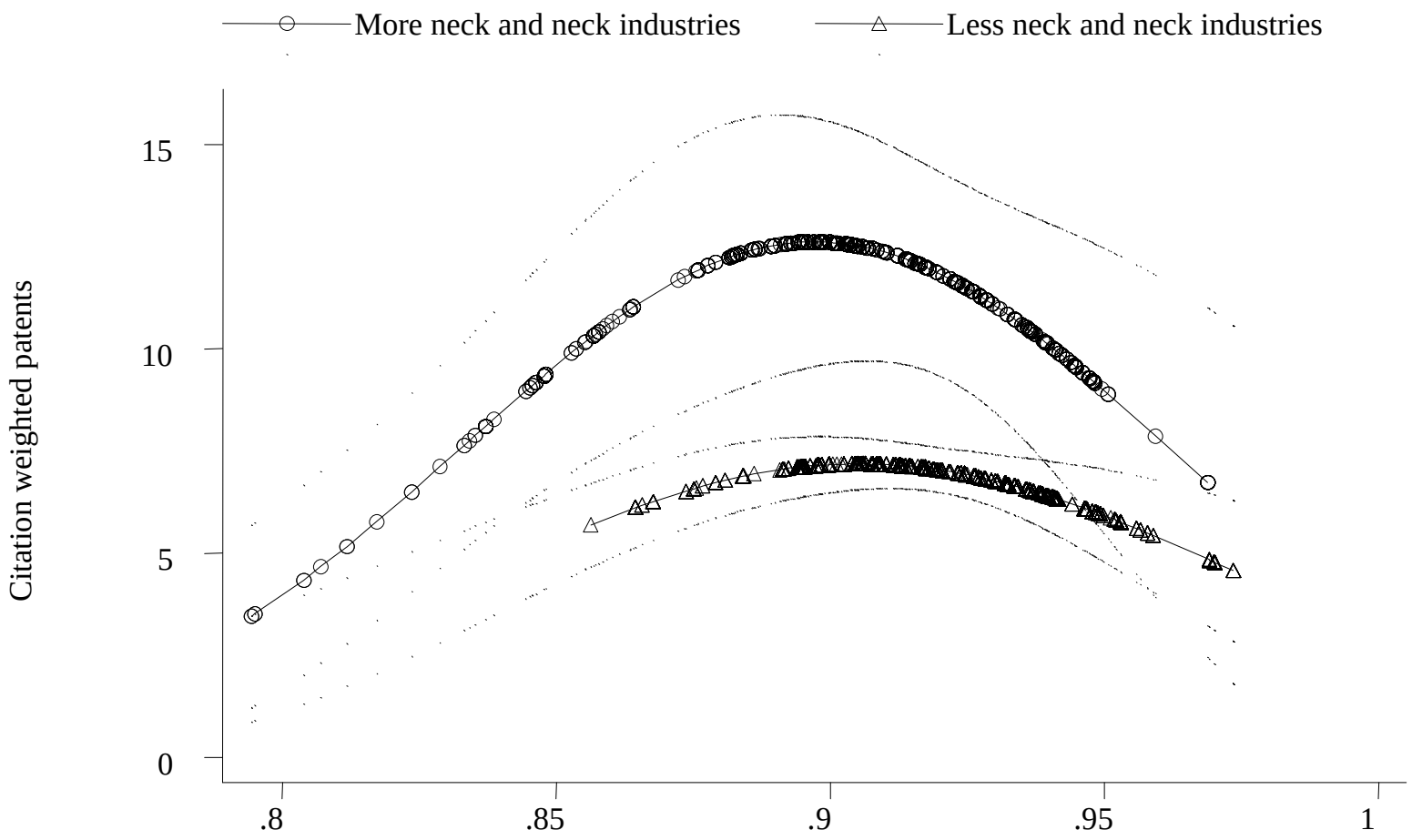


Figure A6.5b: Neck and neck split, controlling for endogeneity of Lerner and split using control function

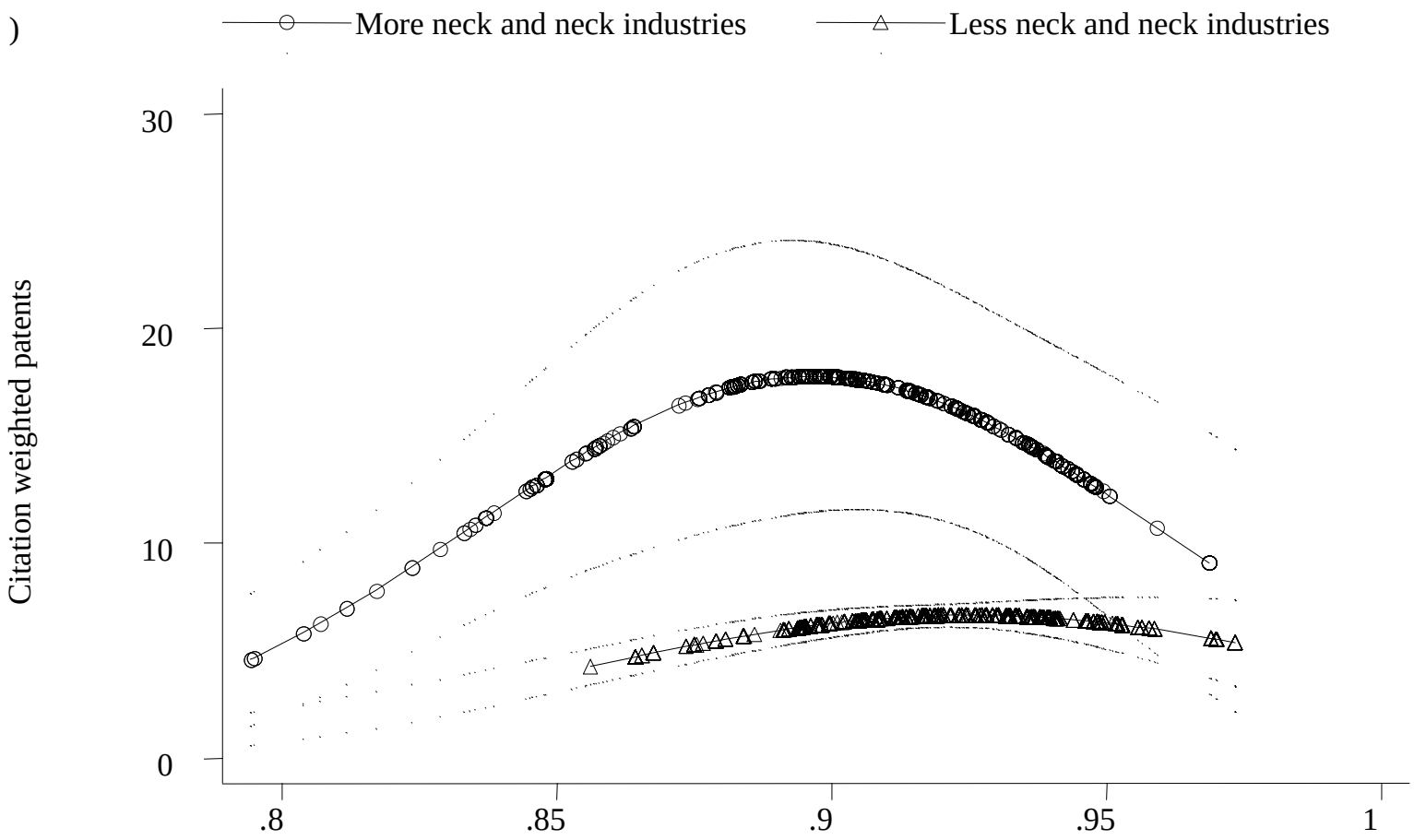


Table 1: Distribution of observations with patents data by industry

Industry	Accounting data only	Accounting and patent data	Total
22 Metal manufacturing	155	123	278
	55.76	44.24	100.00
23 Extraction of other	17	34	51
	33.33	66.67	100.00
24 Non-Metallic Mineral	320	200	520
	61.54	38.46	100.00
25 Chemicals	222	348	570
	38.95	61.05	100.00
31 Manufacture of metal	210	273	483
	43.48	56.52	100.00
32 Mechanical engineering	917	783	1700
	53.94	46.06	100.00
33 Office & Computing	72	31	103
	69.90	30.10	100.00
34 Electrical and electronic	554	484	1038
	53.37	46.63	100.00
35 Motor vehicles	318	210	528
	60.23	39.77	100.00
36 Manufacture of other	133	117	250
	53.20	46.80	100.00
37 Instrument engineering	45	48	93
	48.39	51.61	100.00
41 Food manufacture	209	112	321
	65.11	34.89	100.00
42 Sugar Beverages &	329	259	588
	55.95	44.05	100.00
43 Textiles	458	310	768
	59.64	40.36	100.00
45 Footwear and cloth	397	0	397
	100.00	0.00	100.00
46 Wood Products & Furniture	300	0	300
	100.00	0.00	100.00
47 Paper and Paper Products	564	241	805
	70.06	29.94	100.00
48 Rubber & Plastic	146	117	263
	55.51	44.49	100.00
49 Other manufacturing	227	51	278
	81.65	18.35	100.00
Total	9418	4523	13941
	67.56	32.44	100.00

Table 2: Lerner index and patent counts by industry

Industry	Average firm level Lerner Index		Average number of annual patents
	Accounting data only	Sample with accounting and patent data	
14 Mineral oil processing	0.074		0
22 Metal manufacturing	0.060	0.053	13
23 Extraction of other minerals	0.153	0.183	9
24 Non-Metallic Mineral Products	0.077	0.114	40
25 Chemicals	0.092	0.100	330
31 Manufacture of metal goods	0.082	0.068	2
32 Mechanical engineering	0.074	0.076	55
33 Office & Computing Machinery	0.133	0.111	8
34 Electrical and electronic engineering	0.090	0.093	145
35 Motor vehicles	0.045	0.061	167
36 Manufacture of other	0.071	0.095	36
37 Instrument engineering	0.106	0.077	4
41 Food manufacture	0.060	0.068	15
42 Sugar Beverages & Tobacco	0.104	0.091	113
43 Textiles	0.062	0.075	3
45 Footwear and clothing	0.078		0
46 Wood Products & Furniture	0.077		0
47 Paper Paper Products & Printing	0.092	0.085	3
48 Rubber & Plastic Products	0.104	0.066	4
49 Other manufacturing	0.080	0.088	14
Total	0.077	0.079	

Table 3: Descriptive Statistics

	Mean (s.d)	Median	Min	Max
Patents	7.45 (30.77)	0	0	409
Cite weighted patents	7.45 (30.05)	0	0	392
(1-Lerner)	0.91 (0.025)	0.91	0.79	0.97
Employment (1000s)	11 (28.8)	1.5	0.04	312
Observations per firm	15.7 (5.34)	17	5	22
Technology gap (m)	0.80 (0.189)	0.89	0.004	0.98
Financial pressure	0.066 (2.85)	0.15	0	1

Table 4a: Regression results

Figure:	**Figure 6.1a**	**Figure 6.1b**	**Figure 6.2a**	**Figure 6.2b**	**Figure 6.2c**	**Figure 6.2d**
Observations	3248	3248	2662	3248	3248	1162
c_{jt}	232.0 (12.12)	107.5 (16.35)	263.4 (18.31)	156.9 (27.71)	115.7 (18.49)	292.1 (141.5)
c_{jt}^2	-133.3 (6.75)	-60.1 (9.20)	-142.5 (10.28)	-83.6 (14.86)	-64.04 (10.33)	-165.3 (78.4)
Significance of:						
c_{jt}, c_{jt}^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0457
Year effects	-	0.0000	0.0000	0.0000	0.0000	0.0076
Industry effects	-	0.0000	0.0000	0.0000	0.0000	0.0000

Notes: Significance test shows P-value from c^2 test of joint significance.

Figure 6.1a: Quadratic and spline with no controls
Figure 6.1b: Quadratic and spline with year and industry effects
Figure 6.2a: Conditioning on firm level capital stock
Figure 6.2b: Quadratic with year and industry effects, with Lerner corrected for fixed costs
Figure 6.2c: Using alpha rather than 1-Lerner
Figure 6.2d: Using R&D instead of patents (1980-1994; main sample 1990-1994)

Table 4b: Regression results

Figure:	**Figure 6.4**		**Figure 6.5a, 6.5b (solid line)**	**Figure 6.5a**		**Figure 6.5b**	
	high	low	-	high	low	high	low
	1288	1960	2491	926	1565	926	1565
c_{jt}	112.0 (25.0)	218.6 (33.94)	159.7 (36.37)	374.7 (82.2)	299.1 (51.1)	453.5 (83.5)	453.6 (40.7)
c_{jt}^2	-60.6 (14.16)	-121.5 (18.71)	-87.41 (20.49)	-211.1 (46.6)	-165.9 (28.6)	-255.9 (47.4)	-257.4 (22.5)
Significance of:							
c_{jt}, c_{jt}^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
year effects	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000
industry effects	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
instruments in reduced form for c_{jt}			0.0000	0.0000	0.0000	0.0000	0.0000
instruments in reduced form for c_{jt}^2			0.0000	0.0000		0.0000	
instruments in reduced form for split	-	-	-	-		0.0000	
control functions in regression	-		0.0000	0.0000	0.0000	0.0000	0.0000
R^2 of reduced form for c_{jt}			0.8649	0.8667		0.8649	
R^2 of reduced form for c_{jt}^2			0.8668	0.8685		0.8668	
R^2 of reduced form	-	-	-	-		0.5433	

Notes: Significance test shows P-value from c^2 test of joint significance. Excluded variables are: policy instruments discussed in section 5.2, imports over value-added in same industry-year in USA and France, TFP in same industry-year in USA and France, output minus variable costs over output in same industry-year in USA and France, estimate of markup from industry-country regression for USA and France (Martins et al 1996) interacted with time trend.

Figure 6.4: Neck and neck split (by TFP)

Figure 6.5a: Neck and neck split, controlling for endogeneity of Lerner using control function

Figure 6.5b: Neck and neck split, controlling for endogeneity of Lerner and split using control function

Table 4c: Regression results

Figure:	**Figure 6.6a**	**Figure 6.6b**
	2662	2662
c_{jt}	253.7 (25.5)	313.1 (44.3)
c_{jt}^2	-142.9 (14.3)	-174.2 (24.9)
c_{jt} *(financial pressure)	-157.4 (27.1)	-248.4 (35.7)
c_{jt}^2 *(financial pressure)	89.6 (15.0)	139.2 (19.8)
Financial pressure	69.3 (12.1)	111.0 (16.1)
Significance of:		
c_{jt}, c_{jt}^2	0.0000	0.0000
year effects	0.0000	0.0000
industry effects	0.0000	0.0000
instruments in reduced form for c_{jt}		0.0000
instruments in reduced form for c_{jt}^2		0.0000
control functions in regression		0.0000
R^2 of reduced form for c_{jt}		0.8550
R^2 of reduced form for c_{jt}^2		0.8570

Notes: Significance test shows P-value from c^2 test of joint significance. Excluded variables are: policy instruments discussed in section 5.2, imports over value-added in same industry-year in USA and France, TFP in same industry-year in USA and France, output minus variable costs over output in same industry-year in USA and France, estimate of markup from industry-country regression for USA and France (Martins et al 1996) interacted with time trend.

Figure 6.6a: Financial pressure split

Figure 6.6b: Financial pressure split, controlling for endogeneity of Lerner using control function