Worker Safety and Market Dynamics

by
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Abstract

The thesis consists of two self-contained papers. The first is an empirical paper and concerns the estimation of the marginal willingness to pay for workplace safety. The second paper is theoretical and concerns the dynamic behavior of optimum quantities in a Cournot duopoly market where the firms operate under capacity constraints.

The aim of paper [1] is to empirically estimate the monetary value workers place on safer working conditions. Retrospective data from the Swedish Level of Living Survey contain information on job durations. These data are used together with data on accident risks and wages to determine the marginal willingness to pay for workplace safety. The marginal willingness to pay is allowed to vary between groups. The results indicate that individuals value safety to 0.65-4.1 percent of annual wages.

Paper [2] consider the dynamics in a Cournot model where the two firms operate under capacity constraints and the demand function they face is iso-elastic. It is shown that there is a period doubling cascade to chaos when the Cournot point looses stability. The case of adaptive adjustment is also considered. The Cournot point will then loose stability through a subcritical Neimark bifurcation. The method of critical lines is used to get an outline of one chaotic looking attractor that is coexisting with the stable Cournot point.

Keywords: Search; Hedonic wages; Work injuries; Accelerated duration; Cournot Duopoly; Dynamic Analysis; Chaos
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This thesis consists of a summary and the following two papers:


2. Cournot Duopoly when the Competitors Operate under Capacity Constraints (co-authored with Tönu Puu). Published in *Chaos, Solitons and Fractals*, 18, (2003), 577-592.
1 Introduction

The thesis consists of two self-contained papers. The first is an empirical paper and concerns the estimation of the marginal willingness to pay for workplace safety. The second paper is theoretical and concerns the dynamic behavior of optimum quantities in a Cournot duopoly market where the firms operate under capacity constraints.

The value of most private goods is measured by their price. In the case of workplace safety, the price is not known. Job safety has been the object of policy and regulations that in many ways have been costly to implement. One could argue, that for a severely injured worker no amount of money in the world could be enough to compensate. But, the prevention of all injuries is probably not feasible and/or would be extremely costly. In for instance policy evaluation, there is a need to know the private value of workplace safety. The price measures how much an individual would be willing to pay to receive an extra unit of the good in question, i.e. the marginal willingness to pay for workplace safety.

An increase in workplace safety could also be beneficial to the firm as workers can be thought to demand increased wages to accept an unsafe job. That there is a trade-off between wages and job safety in the sense that workers can accept lower wages in exchange for safer working conditions originated with Adam Smith in 1776. In the Wealth of Nations (Smith, 1776) he presented what would later be known as the theory of compensating differentials. Workers will demand higher wages in order to accept a risky job or a job with poor working conditions. The costs of improving the work environment could then be offset by firms having lower wage costs. Much interest has been devoted to evaluate the magnitude of these wage differentials for working conditions in general and for work injuries in particular.

Paper [1] uses retrospective data from the Swedish Level of Living Survey to empirically estimate the marginal willingness to pay for workplace safety.
The originating theory behind the second paper is of a more recent date. In 1838, Cournot formulated his theory of quantity setting in a market with only two or a few firms (Cournot, 1897). The object of each of the firms is to determine the profit maximizing output when the price of the good will depend on how much the other firm will produce. Cournot himself did consider his model in dynamic terms. Since each firm makes a guess as to what the other firm’s output will be, they will refine their estimates with time. This will result in a step by step adjustment to the optimal quantities (Varian, 1992).

Later research of the Cournot model reveals a much more complex dynamic behavior than the one considered by Cournot. Paper [2] considers the dynamics in a Cournot model where the two firms operate under capacity constraints and the demand function they face is iso-elastic.

The rest of this overview is organized as follows. In Section 2 the previous literature concerning the valuation of workplace safety is discussed. Section 3 gives a theoretical background to the second paper. Both sections also include a summary of the respective paper.

2 The Private Value of Workplace Safety

Workplace safety has been and is an important concern for public policy and debate. The earliest work injury legislation in Sweden was enacted in 1889. The purpose was to regulate the responsibility of private industries to "...vidtage de anordningar som i afseende å arbetslokaler, maskiner eller redskap eller eljest med hänsyn till arbetets beskaffenhet äro nöliga för att skydda hos honom anställde arbetares lif och helsa" 1 (Danielsson, 1990). Just a few years later the legislation was extended in that workers injured were to be awarded compensation (albeit meagre). The work injury legislation has since been revised a number of times. Additional groups of workers have succeeding been included, and by 1964 all except domestic workers

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1freely translated: "...to adjust work areas, machinery or tools or other necessary to protect the life and health of those employed by him"
were covered by the work injury insurance (Danielsson, 1990). The concept of a work injury has been extended as well. In 1929 the first occupational disease was included in the definition of a work injury. The list of diseases considered as work injuries was in the 1978 reform replaced by a general definition of a work disease making it possible to be awarded compensation for musculo-skeletal as well as psychosocial ailments (Andersson, 1990).

The gradual development of the work injury legislation has not been without debate. Much concern regarding the costs and disadvantages for the employers were shown when the first legislation was to be enacted in 1889. The introduction of a supervisory board (“yrkesinspektion”) was only passed with 107-97 votes in the first chamber. In the early 1970’s, the revision of the legislation sparked much debate and the term ”arbetsmiljö” (work environment) was coined.

A number of methods are available to obtain estimates of the marginal willingness to pay for goods for which prices are not observable. Methods include direct approaches where individuals are asked about their willingness to pay. These methods have the drawback that what individuals say they are willing to pay and what they actually would pay can differ (e.g., Boyle (2003) for a discussion of misleading responses in contingent valuation). The alternative is to use indirect methods, like the one used in paper [1], where the willingness to pay is determined by using information on how individuals actually behave in different situations and based on that information to make inferences regarding their willingness to pay.

The valuation of work injuries have mostly been applied by using hedonic price theory. The basic idea is to use information on an observable price, for instance, the wage, and from that price deduce the unobserved value of different characteristics. The method mostly used to determine the monetary value of job safety has been to estimate wage equations where the wage is determined by the different job characteristics. A recent survey of this field is Viscusi and Aldy (2003). The approach, however, rest on the assumption of perfect competition as pointed out by, e.g., Cahuc
and Zylberberg (2004). The important assumptions of perfect competition are that agents have full information regarding quality and prices and that there is free entry and exit. As Stigler (1962) noted, there is an important problem of lack of information in the labor market and it is this that will give rise to wage dispersion. Stigler (1962) considered instead workers that search for wage offers. His model was static, however, and a dynamic model for search was later to be developed (e.g., Rogerson et al. (2005) for an extensive survey of search-theoretic models of the labor market and Eckstein and van den Berg (2007) for a survey of empirical applications of search theory). Hwang et al. (1992) show that if it is not possible to observe workers human capital, estimates of the compensating differential in a wage equation approach will be biased. The size of this bias can be substantial and may even result in parameter estimates with unexpected signs (Hwang et al., 1992). In a recent paper using Norwegian data, Dale-Olsen (2006) found that search frictions cause a sizeable downward bias when estimating the marginal willingness to pay using a hedonic framework.

An important result by Gronberg and Reed (1984) shows that it is possible to obtain estimates of the marginal willingness to pay based on a search model. Consider a labor market characterized by search. Workers search for a new job to improve on their existing working conditions. They get utility from job offers that are characterized by wages, \( w \), and other job characteristics, \( z \). The job offers are draws from a job offer distribution, \( F(u(w, z)) \). There is also an exogenous probability of a layoff, \( \delta \). The probability of transition from one job to a new job can then be written:

\[
\lambda(u(w, z)) = \delta[1 - F(u(w, z))],
\]

where both \( \delta \) and \( F(u(w, z)) \) can be allowed to depend on time. The transition rate can in this framework yield information about workers monetary valuation of different nonpecuniary job attributes (Gronberg and Reed, 1984). Workers’ marginal willingness to pay for a job attribute can be written

\[
MW P_k = \frac{\partial u(w, z)/\partial z_k}{\partial u(w, z)/\partial w} = \frac{\partial \lambda/\partial z_k}{\partial \lambda/\partial w},
\]
where $w$ is the wage and $z_k$ is one of $k = 1, 2, ..., K$ non-wage attributes. The marginal willingness to pay for job attributes is given by the marginal utility of the job attribute divided by the marginal utility of wages. For a discussion of the conditions under which (2) can be generalized from the basic on-the-job search model, see van Ommeren et al. (2000).

The result of Gronberg and Reed (1984) has, e.g., been used to estimate the marginal willingness to pay for job safety (Dale-Olsen, 2006) and commuting (van Ommeren et al. (2000) and van den Berg and Gorter (1997) among others).

Previous research have generated a wide range of estimates for the magnitude of the marginal willingness to pay for job safety. The value of a statistical injury (VSI) is used to compare marginal willingness to pay estimates across studies. The VSI is the marginal willingness to pay for a reduction of the number of injuries by one. A thorough and fairly recent review of the value of a statistical injury in a hedonic framework is Viscusi and Aldy (2003). Studies using the injury incident rate have estimates of the value of a statistical injury that range from 60 percent of annual wages to almost 400 percent of annual wages.

Summary of paper [1]: Workplace safety: workers’ marginal willingness to pay

The aim of the present paper is to empirically estimate the monetary value workers place on safer working conditions. To estimate the individual willingness to pay for job safety, workers are considered to change jobs during their working life whenever they are offered a job with better work conditions.

Using the result by Gronberg and Reed (1984) (cf. Eq.(2)), the marginal willingness to pay for job safety is estimated. Assuming a flexible generalized gamma specification for the distribution of durations, allows variables to vary with time and parameters to vary over working life.

Information on complete work histories is available from the retrospec-
tive questions in the Swedish Level of Living Survey in 1991. The sample includes all job spells begun since 1970. Information on wages is from official tax registers. The incidence rate for job safety is matched to the work histories using 5-digit industry codes.

The specification is extended to account for heteroscedasticity by allowing variables to affect the scedastic function. The marginal willingness to pay is derived for this case. The marginal willingness to pay will be a function of the variables such that each job spell will have a separate value for the marginal willingness to pay.

The results confirm that workers tend to stay longer in jobs with lower risk rates and higher wages. The average marginal willingness to pay for workplace safety is SEK 415, which is 0.65 percent of annual wages, when workplace safety is measured as the reduction in the number of accidents by 1/1000 employees. This corresponds to a value of a statistical injury of SEK 415,000 (about 650 percent of annual wages). When allowing $MW_P$ estimates to vary across subgroups, only blue-collar workers and males in service occupations have positive and significant effects of risk on expected duration. Blue-collar female workers are on average willing to forego a larger part of their wages to increase workplace safety, 1.32 percent compared to 0.93 percent for male blue-collar workers. The highest $MW_P$ estimates are for male workers in service occupations. They are willing to give up on average SEK 1,703 (4.1 percent of wages) to reduce the number of workplace accidents by 1/1,000 employees.

3 Dynamic Analysis of Cournot Duopoly

In a market with only two firms, price setting will be quite different from price setting under monopoly or perfect competition. Under monopoly, the one and only firm can set the price based on consumer demand. In perfect competition, many small firms will take the price as given. In duopoly, each firm sets the price taking into account not only consumer demand, but will also consider the decisions of the competing firm. This
makes the theory of duopoly more complicated than both monopoly and perfect competition (Puu, 2002) and the price mechanism will not be as easily generalized (Palander, 1939a). The possible outcomes in a market characterized by duopoly are not just variations of a single model. The workings of the price mechanism will be substantially altered as a result of even minor changes in the assumptions (Palander, 1939a,b).

Duopoly, or more generally oligopoly, has mostly been studied in game theoretic frameworks. For a survey of oligopoly models in industrial organization see Shapiro (1989).

In Cournot duopoly, the two firms make a profit-maximizing decision regarding the optimal quantity to supply. The optimal quantity for each firm will then be a function of the output of the other firm. This function is known as the reaction curve. The Cournot outcome is a Nash equilibrium.

When Cournot wrote his article on duopoly in 1838, he was the first to use calculus in economic analysis. It is fitting that when the presence of complex dynamics and chaos was first considered for an economic problem by Rand (1978) it was in a model of Cournot duopoly (Rosser, 2002). Rand considered the case where the firms’ reaction functions were nonlinear and non-monotonic. The completely deterministic system produces periodic orbits of every period and also chaotic attractors. Rand noted that such a system may be interpreted as stochastic when it is in fact completely deterministic and not particularly complex (Rand, 1978). Rand’s article has been followed by many others and the presence of local/global stability has become an important focus in the analysis of the Cournot model during the past two decades (Tramontana et al., 2009).

Dynamic analysis of a Cournot model with firms having capacity limits was first introduced in paper [2], although, already Edgeworth (1897) considered the static analysis of a duopoly with capacity limits. The dynamic behavior of the Cournot model with capacity limits have since paper [2] been extensively studied. In Puu and Ruíz Marín (2006), the case with three firms is considered. Tramontana et al. (2009) extend the model by
allowing each firm to operate several plants. Puu (2008) introduce a different type of cost functions, where capacity limits adjust as the number of competitors increase. The Cournot point is then found to be stable. The Cournot point is also stable in a model where the capacity constraint is the result of one input being fixed in the short run (Puu, 2005; Puu and Panchuk, 2008) and the duopoly equilibrium will seamlessly change into perfect competition when the number of firms increase.

The use of iso-elastic demand functions in the present context was first introduced in Puu (1991). Iso-elastic demand will result when utility functions are of a Cobb-Douglas type. Puu (1991) showed that this type of demand function together with constant unit production costs will result in both periodic and chaotic behavior. The model in Puu (1991) has been further studied by e.g. Ahmed and Agiza (1998). The case where the adjustment to the other firm’s output is adaptive is further studied in Agliari et al. (2005, 2006). Agliari et al. (2006) study the multistability of attractors that occur when there are subcritical Neimark bifucations.

**Summary of paper [2]: Cournot duopoly when the competitors operate under capacity constraints**

This paper considers Cournot duopoly when the competitors have capacity constraints. The two firms face an iso-elastic demand function for the homogenous good. This results in the following reaction functions:

\[
\begin{align*}
    x' &= F(x) := \begin{cases} 
        \frac{1}{2} \sqrt{4uy + 5y^2} - \frac{3}{2}y, & y \leq u \\
        0, & y > u
    \end{cases} \\
    y' &= G(y) := \begin{cases} 
        \frac{1}{2} \sqrt{4vx + 5x^2} - \frac{3}{2}x, & x \leq v \\
        0, & x > v
    \end{cases}
\end{align*}
\]

where the apostrophe denotes the next iterate of the map. The outputs of the two firms are \( x \) and \( y \), respectively, and \( u \) and \( v \) are the capacity limits.

The Cournot point is analytically checked for stability. In the present formulation, the Cournot point is destabilized when there is considerable asymmetry between the firms in terms of their capacity limits. The cost
functions of two firms could easily be modified, however, to reduce the amount of asymmetry needed for complex dynamics to arise, but then closed form solutions would not exist.

Simulations show that once the Cournot point looses stability, it is replaced by a 4-cycle. Then follows a period doubling cascade to chaos, which continues until the critical value for the ratio of capacity limits at which one of the firms starts throwing the other out of business. At that point there seem to be coexistent cycles, predominantly of period twenty.

The system is also simulated using adaptive adjustment. Producers do not immediately jump to their optimum outputs as given by their reaction functions. Instead, they just move a bit of the differences from their previous outputs towards these calculated new best replies, thus showing a little conservatism or disbelief in the optimality of their best replies. The origin and the Cournot point are the only equilibrium points for the adaptive system as well.

There will not be a period doubling cascade to chaos when the Cournot point looses stability in the adaptive model. Instead, it will now loose stability through a Neimark bifurcation. Simulations indicate that the loss of stability is in fact due to a subcritical Neimark bifurcation, i.e. a pair of stable (outer) and unstable (inner) invariant curves are born, first coinciding, then separating with further parameter changes. Separation proceeds until the inner unstable curve collapses around the fixed point and it is this that will finally destabilize the fixed point. The Neimark bifurcation being subcritical implies that it is not possible to stabilize the system at the fixed point through a small adjustment of the parameters or initial conditions.

At the moment of destabilization of the Cournot point it may be that the outer stable invariant curve is located at some distance from the Cournot point, and may already have undergone bifurcations to periodicity or chaos. Simulations indicate that this is indeed the case. Some examples are illustrated showing the presence of periodic regions even when the Cournot point is still stable. Regions of chaotic attractors are also identified outside
these periodic regions. The method of critical lines is used to get an outline of one chaotic looking attractor. The conclusion is that the duopoly model with capacity constraints is able to produce very complex dynamic behavior.
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