Estimation of Production Risk and Risk Preference Function: A Nonparametric Approach

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ABSTRACT

This paper deals with nonparametric estimation of risk preferences of producers when they face uncertainty in production. Uncertainty is modeled in the context of production theory where producers' maximize expected utility of anticipated profit. A multi-stage nonparametric estimation procedure is used to estimate the production function, the output risk function and the risk preference function. No distributional assumption is made on the random term representing production uncertainty. No functional form is assumed on the underlying utility function. The Norwegian salmon farming data are used for an empirical application of the proposed model. Salmon farmers are, in general, risk averse; labor is risk decreasing while capital and feed are risk increasing. Median risk premium is about 5% of mean profit.

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1. Introduction

Risk in production theory is mostly analyzed under (i) output price uncertainty and (ii) production uncertainty (commonly known as production risk). Production uncertainty is quite popular in applied work because it is often explained by inputs. That is, input quantities not only determine the volume of output produced but some of these inputs also affect variability of output (often labeled as production risk). For example, fertilizer might be risk augmenting while labor might decrease output risk. Here we address the implications of production risk in a framework where producers maximize expected utility of anticipated profit. In particular, we examine input allocation decision in the presence of production risk.

Although the theoretical work on risk in the production literature is quite extensive, there are relatively fewer empirical studies devoted to analyzing different sources of risk on production and input allocation. Most of these studies either looked at output price uncertainty (Appelbaum and Ullah (1997), Kumbhakar (2002), Sandmo (1971), Chambers (1983)) or production risk along the Just-Pope (1978) framework (Tveterås (1999, 2000), Asche and Tveterås (1999), Kumbhakar and Tveterås (2002), and many others). To examine producers' behavior under risk some parametric forms of the utility function, production function and output risk function along with specific distributional assumptions on the error term representing risk are considered in the existing literature (Love and Buccola (1991), Saha, Shumway and Talpaz (1994)). Thus, the risk studies in the production literature have some or all of these features built in, viz., (i) parametric forms of the production and risk function, (ii) parametric form of the utility function, (iii) distributional assumption(s) on the error term(s) representing production risk and/or output price uncertainty.

This paper estimates nonparametrically the production function, the risk function and risk preference function associated with production risk. The main advantage of the nonparametric approach used here is that the results are robust to functional form used. In a recent survey Yatchew (1998) argues that economic theory rarely, if ever, specifies precise functional forms for production or risk functions. Consequently, its implications are not, strictly speaking, testable when arbitrary parametric functional forms are specified. To the extent that the production or risk functions are misspecified estimates of risk preference functions may be biased.[1] By using nonparametric technique it is possible to estimate the risk preference function that do not depend on specific functional form of the underlying utility function, the production and output risk functions. Similarly, estimates of producer-specific risk premium are obtained without making any assumptions on the functional form of the underlying utility function.

The rest of the paper is organized as follows. The production risk model is presented in Section 2. Nonparametric estimation of the production, risk and risk preference functions are considered in Section 3. Section 4 describes the Norwegian salmon farming data used in the paper. Empirical results are presented in Section 5. Section 6 concludes the paper with a brief summary of results.

2. A Production Risk Model

Assume that the production technology can be represented by a Just-Pope (1978) form, viz.,

$$y = f(X) + g(X)\boldsymbol{e}, \quad \boldsymbol{e} \sim (0,1) \qquad (1)$$

where y is output, X is a vector of variable inputs and $f(X)$ is the mean output function. Since output variance is represented by $g^2(X)$, the $g(X)$ function is labeled as the output risk function. In this framework an input j is said to be risk increasing (decreasing) if $g_j(X) > (<) 0$.

We consider the case where output and input markets are competitive and their prices are known with certainty. The production is, however, uncertain. Assume that producers maximize expected utility of anticipated profit $E\left(U(\boldsymbol{p}^e)\right)$ to determine optimal input quantities, which in turn determines output supply. Define anticipated profit[2] $\boldsymbol{p}^e$ as

$$\boldsymbol{p}^e = py - rX = pf(X) - rX + pg(X)(\boldsymbol{e}) \equiv m_p + pg(X)\boldsymbol{e} \qquad (2)$$

[1] For an excellent review of nonparametric methods in econometrics, see Pagan and Ullah (1999).

[2] We call it anticipated (instead of actual) profit because $\boldsymbol{p}^e$ in (2) is random.

where $\mu_{\pi} = E(\pi^{e}) = pf(X) - rX$, p being the output price and r the input price vector.

The first-order conditions (FOCs) of expected utility of anticipated profit $E\left(U(\pi^{e})\right)$ maximization can be written as

$$E\left(U'(\pi^{e})\{pf_{j}(X) - r_{j} + pg_{j}(X)\,\varepsilon\}\right) = 0 \tag{3}$$

where $U'(\pi^{e})$ is the marginal utility of anticipated profit, $f_j(X)$ and $g_j(X)$ are partial derivatives of $f(X)$ and $g(X)$ functions with respect to input X_j, respectively.
Rewrite the above FOCs as

$$f_{j}(X) = r_{j}/p - g_{j}(X)\theta(.) \tag{4}$$

where

$$\theta(.) \equiv \frac{E(U'(\pi^{e})\varepsilon)}{E(U'(\pi^{e}))} = Cov(U'(\pi^{e}), \varepsilon) \tag{5}$$

The $\theta(.)$ term in the first-order conditions (4) is the risk preference function associated with production risk. If producers are risk averse then $\theta(.) < 0$ (i.e., an increase in ε increases π^{e} which in turn reduces $U'(\pi^{e})$ since $U''(\pi^{e}) < 0$ (utility function being concave)). Similarly, $\theta(.)$ is positive if producers are risk lovers and is zero for risk neutral producers. It is generally a function of X, p, and r.

The risk preference function $\theta(.)$ plays an important role in input use decisions. This can easily be seen by expressing the FOCs in (4) as

$$f_{j}(X) = \frac{r_{j}}{p}\phi_{j} \tag{6}$$

where $\phi_{j}(.) \equiv 1 - (p/r_{j})g_{j}(x)\theta(.)$. If $g_j(X) > 0$, then for risk averse producers $\phi_j > 1$ which means that producers do not equate marginal product (expected) of an input to the observed price of that input. Since the value of (expected) marginal product of the input X_j exceeds its price $(p\, f_j(X) > r_j)$, a risk averse producer will use the input less relative to a risk neutral producer (*è = 0*). Alternatively, the risk averse producer internalizes cost of the risky input by raising its virtual (shadow) price to $r_j f_j > r_j$. Similarly, if producer A is more risk averse than an otherwise identical producer B (i.e., f_j for A is greater than f_j for B), producer A will use less of input X_j than producer B, *ceteris paribus*.

3. Econometric Model and Estimation

Estimating risk preference function q requires deriving algebraic expressions for q involving unknown parameters and data. This is not always possible without making some assumptions about the functional form of the underlying utility function and distributional assumptions on the error terms. Furthermore, one needs to make assumptions on the functional forms of *f(X)* and *g(X).* All these problems can be avoided if one uses nonparametric techniques to estimate *f(X)* and *g(X)* as well as the risk preference function.

3.1. Estimation of f, g functions and their partial derivatives

Suppose $X_j \in R^d$ $(j = 1,...,n)$ is a vector of explanatory variables (that include both variable and quasi-fixed inputs), and y_j denotes output (the dependent variable). We assume that there is a production function of the form

$$y_j = f(X_j) + v_j \tag{7}$$

where $f : R^d \to R$ is an unspecified functional form, and v_{jt} is an error term. Our objective is to obtain estimates of $f(X)$ and $g(X)$ as general possible. So we do not consider separable specifications that are popular when dimensionality reductions are desired. We use the multivariate kernel method to obtain an estimate of $f(X)$ at a particular point $X \in R^d$ as follows. First, we estimate the density of X $(\tilde{p}(X))$ as:

$$\tilde{p}(X) = (Nh)^{-1} \sum_{i=1}^{N} K_h(X - X_i) = (Nh)^{-1} \sum_{i=1}^{N} \prod_{j=1}^{d} K(Z_j - Z_{ji}) \tag{8}$$

where $K_h(w) = \exp(-\frac{1}{2h^2}(w - w)'\tilde{\Sigma}_X^{-1}(w - w))$ is the $d-$dimensional normal kernel, $h > 0$ is the bandwidth parameter, $K(w) = \exp(-\frac{1}{2}w^2)$ is the standard univariate normal kernel, $\tilde{\Sigma}_X$ is the sample covariance matrix of X_i $(i = 1,.., d)$,

$$Z_i = A(X_i - \overline{X}) / \lambda ,$$

$$A\tilde{\Sigma}_X A = I_d ,$$

$$\overline{X} = N^{-1}\sum_{i=1}^{N} X_i ,$$

and λ is a smoothing parameter. The optimal choices for h and λ are

$$h = \lambda^d \,|\tilde{\Sigma}_X|^{1/2},$$

$$\lambda = \left(\frac{4}{(2d+1)N} \right)^{d+4} .$$

The unknown function is then estimated as

$$\tilde{f}(X) = (Nh)^{-1}\sum_{i=1}^{N} W_{hi}(X)y_i \qquad (9)$$

where

$$W_{hi}(X) \equiv K_h(X - X_i) / \tilde{p}(X)$$

(see Hardle (1990, pp. 33-34). The estimates are adjusted near the boundary using the procedures discussed in Rice (1984), Hardle (1990, pp. 130-132), and Pagan and Ullah (1999, Chapter 3).

First derivatives of $f(X)$ is obtained from

$$\frac{\partial \tilde{f}(X)}{\partial X} = (Nh)^{-1}\sum_{i=1}^{N} \partial W_{hi}(X) y_i / \partial X .$$

More specifically,

$$\partial \tilde{f}(X) / \partial X_j = -(Nh)^{-1}\left[\sum_{i=1}^{`N} G_{ji} K_h(X - X_i) y_i - \tilde{f}(X) \sum_{i=1}^{N} G_{ji} K_h(X - X_i) \right] / \tilde{p}(X) \qquad (10)$$

where

$$G_{ji} = \lambda^{-2} \sum_{k=1}^{d} \tilde{\sigma}_X^{jk} (X_k - X_{ki})$$

and

$$\tilde{\Sigma}_X = \left[\tilde{\sigma}_X^{jk}, j, k = 1,..., d\right].$$

Given the estimate of $\tilde{f}(X_i)$ one can obtain the residuals e_i from $e_i = y_i - \tilde{f}(X_i)$. An estimate of the variance can then be obtained from

$$\tilde{\sigma}^2(X) = (Nh)^{-1} \sum_{i=1}^{N} W_{hi}(X) e_i^2 \tag{11}$$

(see Hardle (1990, p. 100), Pagan and Ullah (1999, pp. 214-215)). Since $g(X) = \tilde{\sigma}(X)$, estimates of the $g(X)$ function and its gradient $\partial g(X)/\partial X$ can be obtained. Alternatively, the $g(X)$ can be obtained from a nonparametric regression of $|e_i|$ on X_i in a second step. The gradient of $g(X)$ could then be obtained by a procedure similar to the one used to obtain the gradient of $f(X)$ in (10)

3.2. Estimation of risk preference functions and risk premium

To estimate the risk preference function $\theta \equiv \theta(X, r/p)$ we rewrite the relationship in (4) as

$$D_j \equiv \frac{\tilde{f}_j(X) - r_j / p}{-\tilde{g}_j(X)} \equiv \zeta(X, r/p) + \eta_j \quad j = 1,..., m \tag{12}$$

where $[\eta_1,...,\eta_m]' \sim (0, \Sigma_\eta)$ and $m \leq d$ is the number of variable inputs. Since D_j is computed using the estimated values of $f_j(X)$ and $g_j(X)$ – the error term η_j captures the discrepancy between the true and estimated values of $\theta \equiv \theta(X, r/p)$. Our objective is to estimate the $\zeta(X, r/p)$ function that will be the estimator of the risk preference function $\theta(.)$.

Equations (12) can be estimated by simple non-parametric regression when $m = 1$. When $m > 1$, the $z(X, r/p)$ function has to be the same across equations. Moreover, for efficiency, these equations must be estimated jointly. In this paper we use the procedure suggested by Yatchew and Bos (1997) to estimate $z(X, r/p)$.

To get a better understanding of the importance of risk preference and the degree of risk aversion among firms, researchers often compute risk premium (RP) defined as the amount of money that would make a producer indifferent between uncertain profit $ð^e$ and certain profit $E(ð^e) - RP$. Taking a first-order approximation of $U\{E(ð^e) - RP\} = U(ì_ð - RP)$ around $RP = 0$, and a second-order approximation of $U(ð^e)$ around $ì_ð$ Antle (1987) and Chavas and Holt (1996) have shown that

$$RP = 0.5\ AR(ì_ð)\ Var(ð^e), \tag{13}$$

where AR is the Arrow-Pratt measure of absolute risk aversion (i.e., $AR = -U''(ì_ð)/U'(ì_ð)$). RP is the risk premium which is the implicit cost of private risk taking.

Using the definition in (13), the formula for risk premium ca be expressed as:

$$RP = -\tfrac{1}{2} q(.)\ p\ g(X) \tag{14}$$

4. An Application to Norwegian Salmon Farming

The model presented in the preceding sections is applied to Norwegian salmon farms. Norway, the UK and Chile are the largest producers of farmed Atlantic salmon (Bjørndal (1990), Asche (2001)). Salmon farming is more risky than most other types of meat production. Biophysical factors such as fish diseases, sea temperatures, toxic algae, wave and wind conditions, and salmon fingerling quality are major sources of output risk.

It is believed that the effect of biophysical shocks on output risk can be influenced through the input levels, although fish farmers cannot prevent such exogenous shocks. The most important input in salmon farming is fish feed. Feed is expected to increase the level of output risk, ceteris paribus. The salmon cannot digest all the feed, and the residue is released into the environment as feed waste or faeces. This organic waste consumes oxygen, and thus competes with the salmon for the limited oxygen available in the cages. In addition, feed waste decomposition can produce toxic by-products, such as ammonia. Furthermore, production risk is expected to increase with the quantity of fish released into the cages, due to the increased consumption of oxygen and production of ammonia. We do not have any strong a priori presumptions on the risk effects of capital.

Since 1982 the Norwegian Directorate of Fisheries has compiled salmon farm production data. In the present study we use 2,447 observations on such farms observed during 1988-1992.[3] The output (y) is sales (in thousand kilograms) of salmon and the stock (in thousand kilograms) left at the pen at the end of the year. The input variables are: feed (F), labor (L), and capital (K). Feed is a composite measure of salmon feed measured in thousand kilograms. Labor is total hours of work (in thousand hours). Capital is the replacement value (in real terms) of pens, buildings, feeding equipment, etc. Price of salmon is the market price of salmon per kilogram in real Norwegian Kronors (NOK). The wage rate (in real NOK) is obtained by dividing labor cost by hours of labor. Price of feed is obtained by dividing the cost of feed by the quantity of feed.

In the present study labor and feed are treated as variable inputs. Capital is treated as a quasi-fixed input primarily because price data on it is not available. Moreover, since capital stock adjustment is not instantaneous it is perhaps better to treat capital as a quasi-fixed input, especially in the static model like the one used in the present study.

5. Empirical Results

First we report the estimated elasticities of the mean output function ($f(X)$) with respect to labor, capital, and feed. We plot the empirical distribution of these elasticities for labor, capital and feed in Figure 1.[4] The mean values of these elasticities are: 0.029, 0.017, and 0.253, respectively. It can be seen that none of the distributions is symmetric. In fact they are all skewed to the right. Thus the median values of these elasticities are less than their mean values (median elasticities of output

[3] We thank R. Tveterås for providing the data. Details on the sample and construction of the variables used here can be found in the Ph.D.dissertation (Tveterås, 1996).

with respect to labor, capital and feed are 0.017, 0.007 and 0.158, respectively). The standard deviations of these elasticities are: 0.078, 0.046, and 0.282, respectively.

Farm age is found to have a negative effect on mean output. The elasticity with respect to age is expected to be positive, especially when one associates age of the farmer with experience, knowledge and learning. With an increase in experience and knowledge one would expect output to increase, ceteris paribus. However, salmon farm studies show that the marine environment around the farm tends to become more disease prone over time due to accumulation of organic sediments below the cages, leading to oxygen loss and increased risk of fish diseases. Hence, the farm age variable may capture both the positive learning effect and the negative disease proneness effect. According to our results, the negative disease proneness effect seems to dominate. The median (mean) value of age elasticity is -0.003 (–0.002) with a standard deviation of 0.004. Similar result is found in parametric studies (Kumbhakar and Tveterås, 2002).

In production models the time variable is included to capture exogenous technical change (a shift in the production function, ceteris paribus). In the present model we define technical progress in terms of the mean output function, i.e., $TC = \partial \ln f(X)/\partial t = \{\partial f(X)/\partial t\}\{1/f(X)\}$ where $f(X)$ and its time derivative are replaced by their estimated values. Based on this formula we find mean technical progress at the rate of 4.6% per year. The frequency distribution of TC is given in Figure 1. The distribution is skewed to the left. The average rate of TC for most of the farms is around 6%. The median value of TC is 5.3% with a standard deviation of 0.026. A notable feature of this distribution is that it is bimodal. The two modal values of TC are 2.5% and 7.5% per annum, respectively. Although the mean TC is around 6% per year, some farms experienced technical progress at the rate of 2.5% while other "leading" farms experienced a much higher rate.

In farmed salmon production, risk plays an important part. Consequently, it is important to know which input(s) is (are) risk increasing (decreasing). For this we estimate the partial derivatives of production risk, the $g(X)$ function. Based on the estimates of the risk functions we find that labor is,

[4] These elasticities are positive for most of the data points. There are some farms for which the elasticities are negative, especially for labor and capital. This type of violation of the properties of the underlying production technology (viz., positive marginal product) happens when one uses a flexible parametric production function such as the translog. It is, however, possible to eliminate negative marginal products by restricting them with their lowest allowable bound (zero), see Pagan and Ullah (1999, pp. 175-176).

in general, risk reducing. Labor plays a particularly important role in production risk management. Farm workers' main tasks are monitoring of live fish in the pens, biophysical variables (sea temperature, salinity, oxygen concentration, algae concentrations, etc.), and the condition of the physical production equipment (pens, nets, feeding equipment, anchoring equipment, etc.). Thus workers' ability to detect and diagnose abnormal fish behavior, detect changes in biophysical variables and make prognoses on future development, are crucial to mitigate adverse production condition and reduce production risk. We find (as expected) feed to increase the level of output risk, *ceteris paribus*. The feed is not all digested and the residue is released into the environment as feed waste or faeces. This organic waste consumes oxygen, and thus competes with the salmon for the oxygen available in the cages. In addition, feed waste also leads to production of toxic by-products, such as ammonia.

In Figure 2 we report the frequency distribution of elasticities of the risk function with respect to labor, capital, feed, age and time. The mean (median) values of these elasticities for labor, capital, feed, age and time are: -0.049 (-0.043), 0.016 (0.011), 0.085 (0.016), -0.001 (-0.001), and 0.002 (0.002), respectively. The risk part of the production technology seems to be quite insensitive to changes in the age (experience) of farmers. Similarly, no significant change in production risk took place over time.

Elasticities of the mean output and risk functions for each input are derived from the estimates of the $f(X)$ and the $g(X)$ functions and their partial derivatives. We use the estimated values of $f(X)$ and $g(X)$ and their partial derivatives to obtain estimates of the risk preference function *è*(.) and estimates of risk premium (RP) in the second step. Since RP gives a direct and more readily interpretable result, reporting of RP is often preferred. Given that the RP measure is dependent on units of measurement, a relative measure of RP (defined as RRP = RP/ìð) is reported. Relative risk premium (RRP) is independent of the units of measurement. RRP also takes farm heterogeneity into account by expressing RP in percentage terms.

The frequency distribution of RRP is reported in Figure 3. The distribution is skewed to the right. The mean (median) values of RRP are 0.252 and 0.224. RP shows how much a risk averse farm is willing to pay to insure against uncertain profit due to production risk. The RRP, on the other hand, shows what percent of mean profit a risk averse farm is willing to pay as insurance. The above results show that on average a farm is willing to pay about 25.22% of the mean profit as an insurance against possible profit loss due to production risk.

Numerical values of means and standard deviations of elasticities, q and RRP are reported in Tables 1 and 2. In Table 2, we also report the 95% confidence intervals for q and RRP. These confidence intervals are too wide indicating the presence of considerable heterogeneity among salmon farmers regarding their attitude towards risk.

6. Summary and Conclusions

This paper deals with nonparametric estimation of production risk. We consider an approach in which producers maximize expected utility of anticipated profit to solve input allocation problem. In contrast to the risk studies in the production literature that are based on built-in features such as (i) parametric forms of the production and risk function, (ii) parametric form of the utility function, (iii) distributional assumption(s) on the error term(s) representing output risk, our nonparametric approach avoid all these restrictive features. We estimate the production function, the risk function (output risk), and risk preference function nonparametrically and avoid making any functional form assumption on them. Furthermore, we do not make any distributional assumption on the error term representing production risk.

We choose salmon farming for an application because salmon farming is riskier than other types of meat production, e.g., beef and poultry. Based on a sample of 2447 Norwegian salmon farms, we find that labor is risk reducing, while capital and feed are risk increasing. We also find that the salmon farmers are mostly risk averse. This risk averse behavior is expected due to sunk costs related to investments in capital equipment and labor training; high operating capital requirements due to the long time lag between the release and harvesting of salmon; and use of personal assets as security for loans or investment capital. Finally, we report farm-specific values of risk premium (as a percent of profit) to examine the cost of private risk bearing. These risk premiums are positive, but vary among farms, and over time. The median value of relative risk premium is found to be 25.22% – thereby meaning that, on average, farms are willing to pay about 25.33% of their mean profit as insurance to protect against profit losses due to production risk.

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Table 1. Elasticities of the mean production and production risk function

$f(x)$ w.r.t.	Mean	Median	std. dev.
Labor	0.029	0.017	0.078
Capital	0.017	0.007	0.046
Feed	0.253	0.158	0.282
Time	0.046	0.053	0.026
Age	-0.002	-0.003	0.0036
$g(x)$ w.r.t.			
Labor	-0.0493	-0.0427	0.044
Capital	0.0163	0.0109	0.028
Feed	0.0851	0.0159	0.216
Time	0.0024	0.0021	0.0038
Age	-0.0009	-0.0011	0.0014

Table 2. Risk preference and relative risk premium

	Mean	Median	std. dev.	95% confidence interval	
q	-2.869	-2.888	0.435	-3.970	-2.810
RRP	0.252	0.224	0.124	0.122	0.592

Figure 1. Distributions of $f(x)$ elasticities

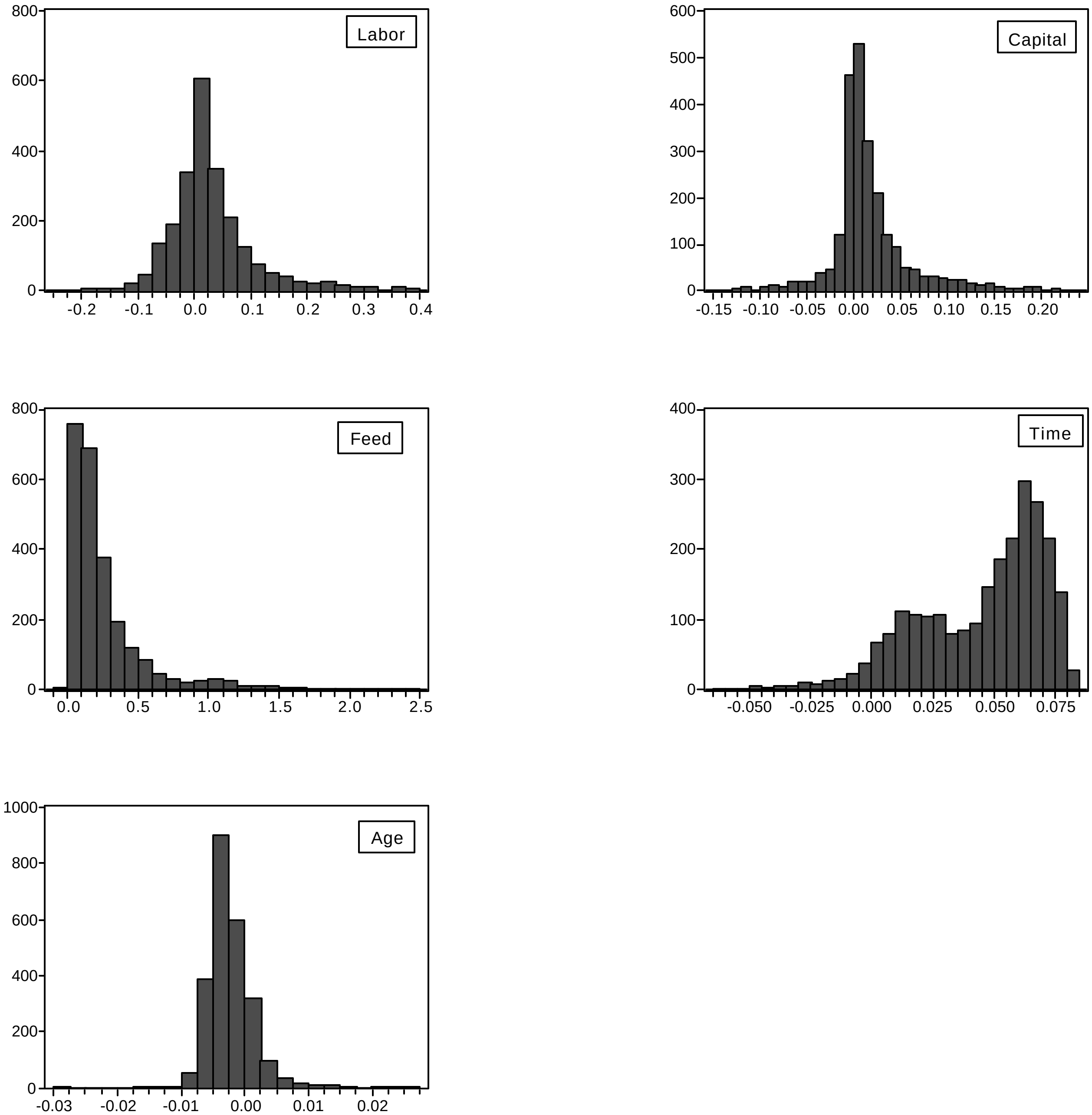

Figure 2. Distributions of $g(x)$ elasticities

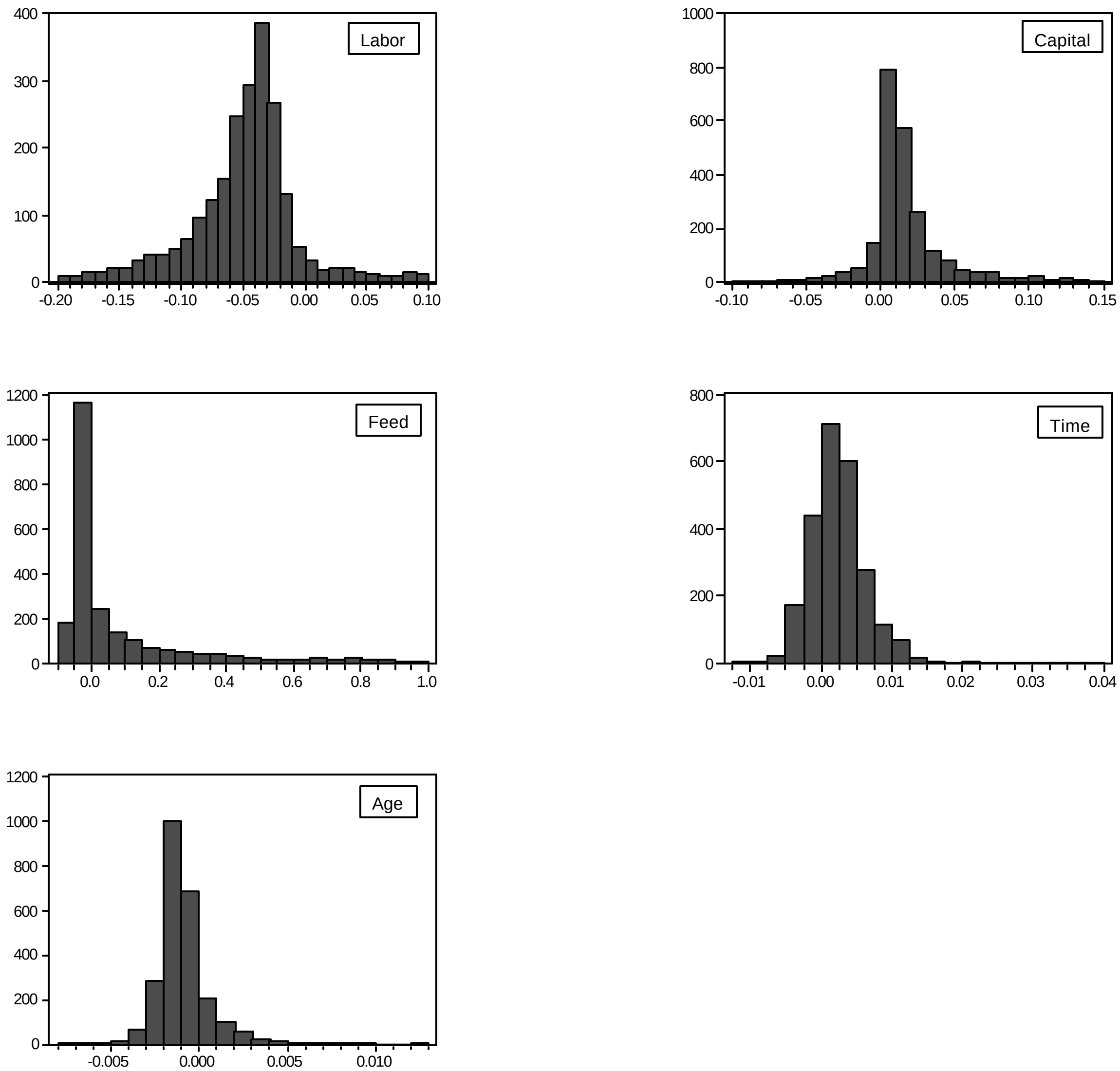

Figure 3. Distributions of relative risk premium