PIECE RATES WITH ENDOGENOUS MONITORING: Some Theory and Evidence
by
Felix R. FITZROY * and Kornelius KRAFT **

* Science Centre, Berlin
** Kassel University, F. R. G.

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Piece Rates with Endogenous Monitoring: Some Theory and Evidence

Felix R. FitzRoy* and Kornelius Kraft**

* European University Institute, Florence, and Science Centre, Berlin
** Kassel University, F.R.G.

Abstract

A model of piece rates under uncertainty with endogenous monitoring which yields a realistic combination of positive time and piece rates in competitive equilibrium is developed, contrasting with customary models yielding a negative time rate unless an arbitrary constraint is imposed. Piece rates and earnings need not be monotonically related to exogenous skill or task complexity in equilibrium. Empirical tests confirmed non-monoticity, but surprisingly found very weak overall effects of piece rates. Greater conflict potential of piece pay is supported by a positive relationship with unionization and probability of a works council.
1. Introduction

Most payment systems in firms involve a mixture of performance-related rewards or incentive pay, and a basic wage or time-rate which depends primarily on the job classification and on personal characteristics such as seniority. Microanalysis of incentive and welfare effects is clearly important to understanding both the behaviour of the firm and of labour markets in the aggregate, yet there has been remarkably little empirical testing of standard assumptions and theories with appropriate microdata. In contrast to this neglect, there has been considerable theoretical progress in the understanding of incentives in the firm, starting with the stimulating contribution of Stiglitz (1975), who argued that risk aversion and the difficulty of monitoring true output (including quality) should reduce piece rates relative to time rates. This suggests that monitoring itself should be treated as an endogenous variable which is determined by the firm as part of an optimal contract. While recent writers such as Eaton and White (1984) and Ordover and Shapiro (1984) do model endogenous monitoring, a problem with their models discussed further below is that they have to restrict pay to the empirically rare case of a pure piece rate.

Discontinuous incentives (prizes and penalties) are also important in practice, and have been studied by Lazear and Rosen (1981), Nalebuff and Stiglitz (1983) and others under the assumption that monitoring and technology are exogenously given. In the absence of piece rates there is presumably always some minimal performance standard which job-holders have to meet, and there may
also be 'prizes' in the form of promotion possibilities even when explicit bonuses are not paid. Monitoring in some form or other is thus always necessary, though continuous quantification of performance for piece pay is likely to require more intensive monitoring in most circumstances.

Monitoring cost can plausibly be reduced through the long-term association of workers with specific skills (FitzRoy and Mueller, 1984; Williamson, 1985). On the other hand, machine-paced work involving repetitive tasks and little skill can also economize on the costs of supervision (Edwards, 1979). Piece rates may then be irrelevant, and the simple negative relationship between use of piece rates and skill or task complexity does not necessarily hold.

In this paper we first criticize the usual models of endogenous monitoring for their failure to generate an interior solution with a positive time rate as well as a piece rate. We then develop an alternative model without this drawback which also yields some testable implications (section 2). In section 3 we describe a data set containing information on piece rates and proxies for skill. OLS and Tobit regression results are presented in section 4, and a summary conclusion follows.
2. Models of Incentives with Endogenous Monitoring

A. Critique of the standard model

The standard model of incentive pay under uncertainty\(^1\) assumes there is some probability, say \(P > 0\), of observing true output or effort, \(e > 0\), which can then be rewarded with a piece rate, \(p > 0\), and a basic (time) wage, \(w\), to yield income

\[
y_0 = pe + w. \tag{1}
\]

When effort is unobserved with probability \(1-P\), a wage-income = \(z > 0\) is paid. Assume for simplicity that the worker has a well behaved,\(^2\) separable utility function given by

\[
U(e, y) = u(y) - D(e), \tag{2}
\]

so that expected utility when the worker chooses effort = \(e\) is

\[
V = Pu(y_0) + (1-P) u(z) - D(e). \tag{3}
\]

The worker then chooses optimal effort \(\hat{e}\) to satisfy the first-order condition on (3),

\[
Ppu'(y_0) = D'(\hat{e}), \tag{4}
\]

where \(y_0 = pe + w\), and optimal \(\hat{e} = \hat{e}(P,p,w)\) for all positive \(P < 1\).
Next, we assume constant returns to workers and a production function of effort

\[ q = q(e), \quad (5) \]

which is concave increasing. Neglecting monitoring costs for the moment, the employer is then assumed to maximize profit per worker by choice of pay parameter, while holding expected utility constant. The Lagrangian for this problem can be written

\[ L = q(e) - Py_0 - (1-P) z + μ(V-A), \quad (6) \]

where \( A \) is alternative utility. Writing down the first-order conditions with respect to \( P, p, w \) and setting

\[ z = \hat{y}_0 = \hat{y}, \quad (7) \]

say, yields the usual efficiency condition of equality between marginal product and marginal rate of substitution, or

\[ q'(\hat{e}) = D'(\hat{e}) / u'(\hat{y}). \quad (8) \]

But comparison with (4) shows that optimal parameters then satisfy

\[ Pp = q'(\hat{e}), \quad (9) \]

and the model can be closed by requiring zero expected profit in competitive equilibrium.
A surprising and somewhat disturbing feature of this model is that, in spite of uncertainty, the solution (7)-(8) is in fact first-best; there is no risk for workers, who always provide optimal effort. Indeed, this can hold for any positive probability $P$, for under appropriate assumptions, (9) can then be solved for $p = \hat{p}(P,w)$, say, and $w$ can then be chosen to satisfy the zero-profit condition.³ The catch is that the wage $w$ may then be negative, and to avoid this unrealistic case, the fixed wage is usually constrained to be non-negative.

Matters become even more unsatisfactory when monitoring costs are introduced. Suppose there is a convex increasing cost $M(P)$ with $M(0)=0$ for observing true effort with probability $P$. Then without a lower bound on the wage ($w$) there is no interior solution in general. Lowering $P$ always reduces monitoring cost otherwise for any $P>0$, but of course the solution breaks down with no observation, or $P=0$. In this case the non-negativity constraint on $w$ leads to a solution with optimal $w=0$, and payment by a pure piece rate, which is also rather unrealistic.

The problem with monitoring cost can be illustrated most simply with the special case of risk-neutral workers. For efficient contracts, competitive firms will maximize expected utility subject to zero expected profits, so the Lagrangian is now

$$L = P(\hat{e}p + w) + (1-P) z - D(\hat{e}) + \mu (q(\hat{e}) - P\hat{y}_0 - (1-P) z) - M.$$ (10)

Clearly, $L_z=0$ implies $\mu=1$ (denoting partials by subscripts), and the basic efficiency condition, which is now
D'(\hat{e}) = q'(\hat{e}), \quad (11)

follows from \( L_w \) and \( L_p = 0 \). But then

\[
L_p = (-D' + q')e_p - M'(P) = - M' < 0, \quad (12)
\]

so there is no interior solution with \( P > 0 \) when marginal monitoring cost is positive for all positive \( P \). Of course, as \( P \to 0 \), it essentially follows from (4) that \( p \to \infty \), so in general the fixed wage \( w \to -\infty \). As remarked above, it is precisely to avoid this quite unrealistic case that an ad hoc constraint such as non-negativity is usually imposed on \( w \).

B. An alternative model

In view of these problems we shall use a different model here, where there is always uncertainty in observing individual effort, but this uncertainty can be reduced by (costly) monitoring. Firms are assumed to produce differentiated products, and average revenue per worker is a known function of true effort, \( e \), and also of a parameter, \( x \). This parameter represents average specific training expenditure per worker necessary for production in each particular firm, and is thus a proxy for the average skill level required to make each product, or for average task complexity. The firm's choice of product, and hence of training expenditure, \( x \), will be taken as historically and technologically given for the present analysis, \(^5\) where we focus on optimal choice of piece rates and monitoring.
To obtain results it seems necessary to use some simple functional forms as follows. A firm with a fixed number of workers is assumed to have revenue per worker

\[ R = ef(x), \]  

(13)

where \( f(x) \) is concave increasing. Next, observed effort per worker is a random variable

\[ \bar{e} = e + \varepsilon, \]  

(14)

where \( e \) is true effort, and the error \( \varepsilon(m, x) \) is a decreasing function of monitoring, \( m \), and an increasing function of task complexity, \( x \). We assume that observation is unbiased, so that

\[ E\varepsilon = 0, \]  

(15)

where \( E \) is the expectation over a known distribution. It follows that if workers are paid a fixed wage or time rate, \( w \), and a piece rate, \( p \), per unit of observed effort, then income per unit time is

\[ y = p\bar{e} + w, \]  

(16)

and expected income is

\[ E y = pe + w. \]  

(17)
To proceed we shall assume identical workers with mean-variance utility, and the error-variance (for computational simplicity)

\[ E \varepsilon^2 = \frac{x^2}{2m}. \]  

(18)

A worker's utility can then be written as follows to yield simple solutions:

\[ U = p\tilde{e} + w - \frac{a^2(y-Ey)^2 + e^2}{2}, \]  

(19)

yielding expected utility

\[ V = EU = pe + w - \frac{(apx)^2}{2m} - e^2/2, \]  

(20)

where \( a > 0 \) represents attitude to risk and is monotonically related to Arrow-Pratt risk aversion. The worker's optimal effort, \( \tilde{e} \), is then simply

\[ \tilde{e} = p, \]  

(21)

by the first-order condition on (20).

Subject to the incentive-compatibility condition (21), the firm is now assumed to maximize profit per worker holding expected utility constant. The Lagrangian is

\[ L = \pi + \mu(V-V_0), \]  

(22)
where expected profit is revenue less total wage and non-wage labour cost, and monitoring cost is \( m/2 \) for convenience,

\[
\pi = R(e,x) - x - pe - w - m/2. \tag{23}
\]

In equilibrium with free entry the time rate should be chosen so that \( \pi = 0 \), and expected income per worker is then

\[
y = R(e,x) - x - m/2 = pe + w - x = p^2 + w - x. \tag{24}
\]

An optimal contract or parameters \((m, p)\), which are function of \( x \), can then be obtained by maximizing zero-profit expected utility, which is

\[
V = R(e,x) - x - (m/2) - [(apx)^2/2m] - e^2/2. \tag{25}
\]

The first-order condition \( V_m = 0 \) yields optimal monitoring per worker

\[
m = apx, \tag{26}
\]

where \( p \) is the optimal piece rate. Note that corner solutions with either \( p = 0 \) or \( m = 0 \) cannot generate positive utility, so that if an interior maximum with positive utility exists, the other necessary condition \( V_p = 0 \) must also be satisfied. From (26), (21) and (13) this condition gives

\[
p = f(x) - ax \tag{27}
\]
for all \((a, x)\) such that \(p > 0\).

Then if \(f'(0) > a\), \(p\) is an initially increasing function of \(x\), but \(p\) may subsequently decline. Thus there is no particular reason for a generally negative monotonic relationship, as is often assumed.

Now it is straightforward to calculate equilibrium earnings

\[
y = f(f-ax) - x - ax(f-ax)/2
\]

\[
= \frac{(f-ax)(2f-ax)}{2} - x, \quad (28)
\]

and the fixed wage is

\[
\hat{w} = \hat{y} - \hat{p}^2 = x \left[a(f-ax) - 2\right]/2. \quad (29)
\]

Clearly, \(\hat{y}\) is likely to be non-monotonic in general, and if \(f > ax\), then for large enough \(a\), \(\hat{w}\) will be positive.

This model thus generates some non-trivial and testable predictions. In particular, an interior unconstrained positive wage is possible by (29), and \(\hat{w}\) increases with risk aversion while earnings decline. Finally we have the requirement or restriction on parameters that unobservable utility should be positive in equilibrium, since unemployment would be preferable otherwise. We find that

\[
\hat{V} = \left[(f-ax)^2/2\right] - x. \quad (30)
\]
Clearly, this model offers no insights into the reasons why some firms have no piece rates. Employers can also motivate effort by offering promotion prospects in the long run, as well as by establishing work norms or production quotas as a condition of employment, as mentioned above. Homogeneity and high skill levels of the workforce seem likely to favour the absence of piece rates as well as the long-term attachment which in turn encourages specific training and career patterns. We return to this problem in the empirical section 3 below.

Finally, a development with some theoretical appeal would be to allow workers with differing risk aversion to choose their optimal employer as defined by the skill parameter, x. However, other personal attributes such as ability are also relevant, and the model quickly becomes intractable. For our empirical purposes we assume constant risk aversion (and ability), and note that earnings differences across firms in our sample are extremely small. The parameter x is not easily observable to potential employees searching for a job, so it seems reasonable for our purposes to assume that homogeneous workers choose jobs on the basis of more obvious characteristics such as location, or availability.
3. **Empirical Evidence and Specification**

While our available data are too limited to allow a complete test of the model (which is of course too simple to capture all relevant influences), we can explore some hypotheses of interest in an area where empirical studies since Pencavel (1977) are rare.

In one of the most recent attempts, Seiler (1984) argues that piece rates should be associated with greater variation of earnings. He assumes as self-evident that incentive pay should increase effort, but does not consider the role of technology in relation to monitoring and machine-paced work with time rates, nor does he develop a formal model of incentives and other factors. Comparing firms with and without piece-rate payment schemes, Seiler finds, as expected, that earnings are greater and more dispersed in the former. Seiler argues that the incentive premium is too large to be explained entirely as risk compensation, and concludes that a substantial effort-incentive effect has been confirmed. Most of the workers in Seiler's sample were on an incentive pay scheme, suggesting generally favourable technology and job design. An additional problem is that "most human capital variables are absent" (Seiler, 1984, p. 369), so it is not entirely clear how these results should be interpreted.

The basis for our study is data collected in 65 medium-sized firms in the German metal-working industry. Our unit of observation is hence not individual workers but firms. Of the 65 firms 62 provided data for 1979 and 61 for 1977. 60 percent of the firms had no individual incentive pay, and in the others, piece payment
ranged up to 100 percent of total pay. Although the sample could be assigned to 3 classifications of the metal-working industry, output was heterogeneous, with each firm essentially making (a) different product(s). The data (collected in personal interviews) included proxies for human capital, technology, and market power, and are described in Table 1.

As dependent variables we use annual earnings (piece pay plus time pay), and annual incentive payment. Our theory does not predict an unambiguous relationship between these variables and complexity, and the latter is of course not directly observable. As a proxy we use expenditure on training in the firm (TRAIN) with a quadratic term to capture any non-linearity. The proportion of output exported may be an additional proxy for skill or complexity under the assumption that international market competition favours higher quality products.

The collective "voice" of labour is represented by the Works Council which employees have the right to elect, and which has far-reaching powers under German labour legislation. Firms with a (non-mandatory) Works Council are indicated by a dummy (WOCO). UNION density is a related variable which presumably strengthens the voice of labour in internal negotiations and disputes. Note however that wage bargaining is centralized, though individual employers may offer premiums when the labour market is tight.

Finally, some conventional explanatory variables are dummies for sub-classifications of the metal industry, a time dummy for 1979, and urban-location dummy, and number employed in the firm.
(NEM). The capital ownership share held by top management (CTOP) was also utilized.

Here we shall estimate a wage equation for firms with positive incentive payments (49 observations). Since our variables are unlikely to capture all the determinants of piece rates, a sample-selection bias can arise with OLS regressions in the subsample with positive incentive pay. To correct for this bias we follow Heckman (1979), and estimate the probability of using piece rates with a Probit regression. The density and c.d.f. are used to construct the inverse Mills ratio, which is then added to the wage equation as a correction variable.

In our second regression we attempt to explain the magnitude of incentive pay, using Tobit regression for the whole sample. The best results were obtained without industry or time dummies as reported in Table 2.

4. Results

Incentive pay is positively related to annual wages in our sample in accordance with theory. In the second equation, for piece rates, the proxies for skill or complexity are negative and significant (TRAIN, EXP) while these variables are positively related to earnings. However, the quadratic term (TRAIN^2) is negative in the wage equation. A possible explanation might be that small amounts of training are basic and general, while further training
tends to be specific and thus has no positive effect on earnings. Overall, these results are consistent with our model.

The Heckman correction is negative significant, indicating selection bias as expected. Surprisingly, the urban dummy and number employed were both negative in the wage equation. The Works Council also has a negative effect, as we have discussed elsewhere. An interesting finding is that WOCO and UNION are strongly related to incentive pay, presumably because these institutions of collective voice reduce the transactions costs of setting piece rates. Alternatively, conflict over rate setting could encourage unionization and the formation of a Works Council, and causality might be reversed. Unfortunately, simultaneous estimation is infeasible with our data set.

Another noteworthy finding (in unreported regressions) was that the hourly wage (rate) is not affected by incentive pay in the subsample, so the influence on earnings must be via annual hours worked. Clearly these are part of the total employment contract which includes stochastic overtime with a frequency depending on demand and employment levels as well as "labour hoarding". As one expects from identical mean annual earnings in the two subsamples (with and without piece rates), an equation for annual earnings estimated for the whole sample showed no influence of incentive pay. The effect of piece rates in Table 2 is small and only just significant, and overall we can conclude that the results of piece rates are surprisingly weak, in contrast to previous work as well as historical evidence (Clark, 1984).
5. Conclusions

A simple exploratory model of uncertainty and incentive pay which does not -unrealistically- imply negative or constrained zero time rates has yielded several surprising and even anomalous results. One of these, a non-monotonic relationship between skill or task complexity and total earnings, also emerged in our empirical study. Data limitations precluded a full account, but the uniformity of total earnings under maximum variation of piece rates (from 0 to 100 percent) remains puzzling. In view of the importance of incentives and agency problems in economic theory and practice, there is clearly much scope for testing models with improved microdata.
<table>
<thead>
<tr>
<th>Definition</th>
<th>Abbreviation</th>
<th>Mean value in firms with piece rates</th>
<th>Mean value in firms without piece rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsector dummy (ERM)</td>
<td>ID 2</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td>Subsector dummy (Machinery)</td>
<td>ID 3</td>
<td>0.59</td>
<td>0.70</td>
</tr>
<tr>
<td>Dummy for existence of works council</td>
<td>WOCO</td>
<td>0.96</td>
<td>0.69</td>
</tr>
<tr>
<td>Training expenditure per employee (1000 DM)</td>
<td>TRAIN</td>
<td>0.69</td>
<td>0.97</td>
</tr>
<tr>
<td>Dummy for 1977</td>
<td>TIME</td>
<td>0.49</td>
<td>0.50</td>
</tr>
<tr>
<td>Percentage of workforce unionized</td>
<td>UNION</td>
<td>52.35</td>
<td>27.5</td>
</tr>
<tr>
<td>Share of production</td>
<td>EXP</td>
<td>29.74</td>
<td>30.6</td>
</tr>
<tr>
<td>Dummy for urban location</td>
<td>URB</td>
<td>0.61</td>
<td>0.43</td>
</tr>
<tr>
<td>Number of employees</td>
<td>NEM</td>
<td>999</td>
<td>385</td>
</tr>
<tr>
<td>Dummy = 1 when top management holds at least 25% of capital</td>
<td>CTOP</td>
<td>0.37</td>
<td>0.82</td>
</tr>
<tr>
<td>Yearly wages per worker (1000 DM)</td>
<td>WAGES</td>
<td>25.204</td>
<td>25.649</td>
</tr>
<tr>
<td>Incentive payments per worker and year (1000 DM)</td>
<td>INCENTIVES</td>
<td>12.42</td>
<td>0</td>
</tr>
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Table 2

<table>
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<tr>
<th>Independent variables</th>
<th>Dependent variables Wages</th>
<th>Incentives (Tobit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>3.73</td>
<td>-0.63</td>
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<tr>
<td></td>
<td>(13.12)</td>
<td>(-6.35)</td>
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<tr>
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<td></td>
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<tr>
<td>ID 3</td>
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<td></td>
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<tr>
<td>WOCO</td>
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<td>1.54</td>
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<td></td>
<td>(-2.05)</td>
<td>(3.12)</td>
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<td>TRAIN</td>
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<td></td>
<td>(3.04)</td>
<td>(-1.40)</td>
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<tr>
<td>(TRAIN)²</td>
<td>-0.13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-3.06)</td>
<td></td>
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<tr>
<td>TIME</td>
<td>-0.04</td>
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<td></td>
<td>(-0.88)</td>
<td></td>
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<tr>
<td>INCENTIVES</td>
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<td></td>
<td>(1.94)</td>
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<td>UNION</td>
<td>-0.001</td>
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<td></td>
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<td>(2.22)</td>
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<tr>
<td>EXP</td>
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<td>-0.03</td>
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<td></td>
<td>(1.93)</td>
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<td>URB</td>
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<td></td>
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<td>(2.29)</td>
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<td>(2.76)</td>
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<td>CORRECTION</td>
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<tr>
<td>CTOP</td>
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<td>R²</td>
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<tr>
<td>n</td>
<td>49</td>
<td>123</td>
</tr>
</tbody>
</table>
Footnotes

1. See e.g. Calvo and Wellisz (1979), Eaton and White (1984), and Ordover and Shapiro (1984), who include endogenous monitoring as discussed below.

2. That is, $u$ is concave and $D$ is convex (increasing).

3. For details, see FitzRoy (1985).

4. See the references cited in fn. 1 above.

5. Endogenous $x$ was considered in previous versions, but led to inconclusive results.

6. Hourly earnings for the whole sample estimated in FitzRoy and Kraft (1985) were unaffected by incentive pay. See also remarks at the end of this section.

7. For a description of the German system of industrial relations and the role of the Works Council, see FitzRoy and Kraft (1985, 1986).

8. This point is not discussed by Seiler (1984), who also neglects human capital. Thus, for example, if workers on piece rates were less skilled on average, but also paid a risk premium, these opposing effects might cancel out.

9. This is the first attempt of this kind which we are aware of.

10. In FitzRoy and Kraft (1985, 1986) we argue that the most efficient employers can offer higher wages and working conditions which render the Works Council superfluous. We also find a negative relation between the Works Council and factor productivity, and can thus reject the "efficiency voice theory" of Freeman and Medoff (1984) for our sample, as well as on theoretical ground.
References


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