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A model-based approach to moral hazard in food chains

What contribution do principal-agent-models make to the understanding of food risks induced by opportunistic behaviour?

Eine modellbasierte Annäherung an Moral Hazard in Nahrungsmittelketten

Welchen Beitrag leisten Prinzipal-Agenten-Modelle für das Verständnis verhaltensinduzierter Nahrungsmittelrisiken?

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Abstract

Food risks may be caused by moral hazard, i.e. by opportunistic behaviour of upstream sellers who exploit the fact that many food product qualities remain uncertain to downstream buyers in the course of conventional market transactions (credence qualities). Due to this lack of market transparency buyers run the risk to pay premium prices for inferior products (quality risks); furthermore, they run the risk to use or consume substances which are harmful (health risks). Therefore, they will want to design optimal contracts and controls preventing opportunistic behaviour. Usually, however, buyers cannot contract contingent on the actions of upstream sellers because they cannot observe them directly (information asymmetry).

Motivated by the obviously game-theoretic nature of the problem, we investigate the potential of principal-agent-models for the analysis of food risks induced by opportunistic behaviour. We identify a binary stochastic moral hazard model which is able to represent the microeconomic situation of buyers (principals) and sellers (agents) adequately. On the one hand, the model considers the remuneration costs which are needed to induce compliance. On the other hand, it accounts for direct costs and benefits of control as well as a limited traceability caused by the multiple agents setting of most food risk problems. If we know the costs of compliance, the stochastic relationship between the agent's action and the product quality, and the traceability coefficient, we are able to determine the optimal control intensity and price for any cost of control function and predefined upper limit of the imposable sanction.

For practical applications the main problem will be how to procure empirical data. The manageable data requirements of the binary model qualify it as a ready to use model for future applications: first, it can be used in positive analyses of food chains in order to detect the hot spots where food risks induced by opportunistic behaviour are to be expected for economic reasons. Secondly, it can be used in normative analyses in order to identify contractual designs which induce compliance at minimum costs. Thirdly, it can be used in order to compare the efficiency of different system structures taking into account the costs of change.

Key words

food risk; information asymmetry; moral hazard; opportunistic behaviour; prevention; principal-agent-model; traceability

Zusammenfassung

Nahrungsmittelrisiken entstehen unter anderem dann, wenn opportunistische Akteure der Wertschöpfungskette unter Ausnutzung von Informationsasymmetrien Verhaltensnormen brechen, ohne dass die dadurch negativ beeinflussten Produkteigenschaften (Vertrauenseigenschaften) offensichtlich sind. Aufgrund eines solchen Mangels an Markttransparenz unterliegen Käufer bei jeder Transaktion dem Risiko, minderwertige (Qualitätsrisiko) oder gesundheitsschädliche Produkte (Gesundheitsrisiko) zu kaufen. Aus Sicht der schlechter informierten Käufer geht es darum, ein optimales Vertrags- und Kontrolldesign festzulegen, das opportunistisches Verhalten vorgelagerter Akteure und damit Markversagen ausschließt, obwohl weder die qualitätsbeeinflussenden Aktivitäten noch die Produkteigenschaften direkt beobachtet werden können.

Aufgrund des offensichtlich spieltheoretischen Charakter des Problems wird im vorliegenden Beitrag untersucht, welches grundsätzliche Analysepotenzial Prinzipal-Agenten-Modelle für verhaltensinduzierte Nahrungsmittelrisiken haben. Dazu wird ein binäres stochastisches Moral-Hazard-Modell abgeleitet, das in der Lage ist, die Entscheidungssituation des Käufers (Prinzipals) und des Verkäufers (Agenten) abzubilden. Dieses Modell berücksichtigt die Kosten einer anreizkompatiblen Entlohnung, die Kontrollkosten, verhinderte Schäden durch Aussortierung schadhafter Partien sowie eine begrenzte Rückverfolgbarkeit, die bei den meisten Nahrungsmittelrisiken eine maßgebliche Rolle spielt. Bei Kenntnis der Kosten der Normeinhaltung, des stochastischen Zusammenhangs zwischen dem Verhalten des Agenten und der Produktqualität sowie der prozentualen Rückverfolgbarkeit lässt sich mit Hilfe des Modells z.B. die anreizkompatible und kostenminimale Kombination von Kontrollintensität und Preis für eine gegebene Kontrollkostenfunktion und maximal zulässige Sanktionshöhe bestimmen.

Mit Blick auf praktische Anwendungen bleibt die empirische Datenbeschaffung die große Herausforderung. Aufgrund seiner relativ geringen Datenanforderungen ist das abgeleitete binäre Modell für zukünftige praktische Anwendungen grundsätzlich gut geeignet: Erstens kann es für eine positive Analyse von Wertschöpfungsketten genutzt werden, in dem Sinne, dass diejenigen Stellen bzw. Prozessaktivitäten identifiziert werden können, bei denen die größten ökonomischen Anreize für normwidriges Verhalten vorliegen. Zweitens lässt sich mit Hilfe des Modells eine normative Analyse durchführen mit dem Ziel, ein Vertrags- und Kontrolldesign zu identifizieren, das mit geringsten Kosten Anreize für normgerechtes Verhalten gibt und somit präventiv wirkt. Drittens lässt sich mit seiner Hilfe die Effizienz verschiedener Systemstrukturen im Sinne verschiedener Organisationsformen der Wertschöpfungskette und der Kontrolle unter Berücksichtigung von Veränderungskosten vergleichen.

Schlüsselwörter

Informationsasymmetrie; Moral Hazard; Nahrungsmittelrisiko; opportunistisches Verhalten; Prävention; Prinzipal-Agenten-Modell; Rückverfolgbarkeit

1. Introduction

In the last two decades, numerous food induced health threats and food scandals have emphasized the relevance of uncertainty concerning the properties of food products (credence qualities). Buyers run the risk to use or consume substances which are harmful (health risks) or to pay premium prices for inferior products (quality risks). These two aspects of risk (hereafter jointly referred to as "food risks") are closely related with their origins: technological hazard denotes a genuine lack of knowledge about health risks of certain processes and substances. Moral hazard, in contrast, denotes opportunistic behaviour of upstream sellers in the food chain who exploit information asymmetries and infringe existing regulations or agreements in order to make profits. This could also be interpreted as "market failure for inhomogeneous products". In other words: moral hazard in food chains causes an increased probability of inferior and/or harmful product properties.

The conceptual differentiation between technological hazard and moral hazard generates a meaningful structure and schedule for risk prevention measures: first, genuine technological insights concerning existing production, transport and processing methods must be obtained. Secondly, innovative procedures and technologies which eliminate identified technological hazards must be developed and specified. Thirdly, incentive systems must be designed which induce compliance with specified regulations and standards on all levels.

At present, the advancement of technological knowledge is the focus of scientific activities. However, technological insights gained by natural scientists and medics are in fact necessary, but not sufficient to reduce food risks. To effectively do so, we need to know how misguided economic incentives which induce opportunistic behaviour can be reduced (cf. e.g. HENNESSY et al., 2002; STIGLITZ, 1987).

There are numerous transactions (and contracts) along food supply chains, each involving a seller and a buyer of a certain raw material or (semi-)processed food product. Actions taken by upstream sellers affect the probability distribution of the product properties which represent a relevant output to downstream buyers. The latter, however, cannot contract contingent on actual actions because they cannot observe them directly (asymmetry of information). Motivated by the game-theoretic nature of the problem, we analyze the potential of principal-agent-models (PA-models)[1] for food risk problems caused by opportunistic behaviour.

On the one hand, such models must have the capacity to represent the microeconomic situation of respective buyers and sellers adequately. On the other hand, their complexity must not exceed the availability of empirical data. Starting from a standard and well known incentive problem formulation (chapter 2), we identify different structures of incentive problems (chapter 3) and then strip the standard model, step by step, to the bones (chapter 4). The resulting "Basic PA-Model" is simple enough to be filled with empirical data. However, some modifications will have to be made in order to account for specific characteristics of food risks (chapter 5). The resulting "Specific Food Risk Model" is able to account for a limited output observability and traceability, upper levels of prices and sanctions, and, last but not least, costs of control and reduced damage costs. The consideration of these characteristics in future applications is necessary in order to identify optimal incentive schemes for existing food chains. Leaving the short-term perspective we look at the problem of adverse selection, structural change and system innovation in chapter 6. This perspective of institutional change, however, is not at the core of this paper. We finally close with an outlook in chapter 7.

2. A standard continuous PA-model

Incentive problems have been studied extensively in different contexts: labour contracting (e.g. EPSTEIN, 1991), insurance (e.g. ARNOTT and STIGLITZ, 1987), delegation of decision-making (e.g. MILGROM and ROBERTS, 1992) etc. Hereafter, we exploit the microeconomic structural analogy between labour contracting and transactions in food chains. This structural analogy, which exists although we are obviously studying different economic contexts and actors, will enable us to translate the food risk problem smoothly into a PA-model. This, in turn, allows us to start off with the following archetypal and standard formulation of the incentive problem for labour contracting (cf. RASMUSEN, 1994: 169ff.):

- A (faintly) risk-averse principal whose objective is to maximize his utility offers to a risk-averse agent a labour contract specifying a wage w contingent on the output y: $w = w(y)$.
- Output is a function $y(k, q)$, both of the agent's action resp. effort k and a stochastic influence q. The principal cannot observe the agent's effort but can observe the output.
- If the agent accepts the contract, his utility will be $U(k,w)$. The principal's utility will be $V(y-w)$.
- The opportunity costs of the agent are m; i.e. if he rejects the contract, he will still achieve a so-called reservation utility m. The utility of the principal, in this case, will be zero.

Formally, the principal's incentive problem (design of an output-based wage under uncertainty) can be written as constraint maximisation problem (RASMUSEN, 1994: 176):

$$(1)\quad \underset{w(\cdot)}{Max}\; EV(y(\tilde{k},q)-w(y(\tilde{k},q)))$$

$$(2)\quad s.t.\;\; EU(\tilde{k},w(y(\tilde{k},q)))\geq m \quad \text{(participation const.)}$$

$$(3)\quad \tilde{k}=\arg\max_{k} EU(k,w(y(k,q))) \quad \text{(incentive compatibility const.)}$$

The mathematical formulation pinpoints that both principal and agent maximise their respective objective functions. However, the principal takes into account the expected decisions of the agent, as stated in the participation and incentive compatibility constraints (cf. LAUX, 1995: 100f.). Since the principal's maximisation problem, as stated

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[1] For more information on different settings of PA-models cf. e.g. KREPS (1990), FUDENBERG and TIROLE (1991), MILGROM and ROBERTS (1992), RASMUSEN (1994), LAUX (1995), BRANDES et al. (1997).

above, is not operational[2], GROSSMANN and HART (1983) chose a sequential approach: in a first step, they minimise wages inducing each possible effort level $\tilde{k}$. In a second step, they choose the optimal effort level by maximising the principal's expected utility $EV(\cdot)$.[3] Consequently, the problem may be restated as follows (cf. RASMUSEN, 1994: 176):

$$(4) \quad \underset{w(\cdot)}{Min}\; Ew(y(\tilde{k},q)) = w_{min}(\tilde{k}) \qquad \textbf{Step 1}$$

$$s.t. \text{ (2) and (3)}$$

$$(5) \quad \underset{\tilde{k}}{Max}\; EV(y(\tilde{k},q) - w_{min}(\tilde{k})) \qquad \textbf{Step 2}$$

Most PA-models assume that the principal is less risk-averse than the agent. Furthermore, information is always assumed to be incomplete. This is why the first best solution (pareto-efficient risk allocation) cannot be achieved. However, there is a second best solution which represents the optimal solution and a Bayes-Nash-equilibrium in this world of incomplete information (RASMUSEN, 1994: 175; BRANDES et al., 1997: 345).

3. Different microeconomic structures of incentive problems

The general formulation of the incentive problem used above enables us to understand which variables and parameters actually define the microeconomic structure of the decision problem. Table 1 brings out the fact that the complexity of a PA-model depends on the assumptions concerning the specification of model inputs and model parameters. It should be noted that not all combinations of the listed parameter values bring forth sensible models. For instance, a limited traceability $z < 100$ % only makes sense if we consider more than one agent[4]; similarly, a control intensity $s < 100$ % is only relevant if we take into account costs of control. Furthermore, table 1 implies that the output is the best and only signal or performance measure for the actions of the agent(s).[5]

The hatched fields in table 1 denote the assumptions of the standard PA-model (1) to (3). The shaded fields denote the assumptions of the "Specific Food Risk Model" we are going to specify. Referring to the numbering of table 1 we comment on the differing assumptions:

1./2. Conventional PA-models account for a continuous formulation of state variables such as action or effort, output and wage. For the sake of simplicity, we will at first only consider two states of these variables in the food risk model. This reduces the agent's scope of action (or: effort) to either a low (non-compliance) or high (compliance) effort level. This binary perspective allows us to use simple binomial distributions for variables such as output and wage.

3./4. Conventional PA-models explicitly account for risk aversion by using the concept of risk utility. Since it is nearly impossible to obtain reliable estimates for risk utility functions of individual decision-makers, we assume risk neutral principals *and* agents. Therefore, optimal risk sharing will not be our concern here (cf. LAUX, 1995: 129).

Table 1. The structure of principal agent models

	low ←---complexity of model ---→ high		
1. effort level *k* of the agent	**binary**	**discrete**	**continuous**
2. output *y* and wage *w*	**binary**	**discrete**	**continuous**
3. risk attitude of the agent	**risk-neutral**		**risk-averse**
4. risk attitude of the principal	**risk-neutral**		**risk-averse**
5. possible range of values of reservation utility *m*	***m* = 0**		***m* ³ 0**
6. objective function of principal	**minimising costs**		**maximising utility**
7. functional relationship between effort and output	**deterministic**		**stochastic**
8. observability of the output	**unlimited**		**limited**
9. intensity *s* of output observation (controls)	***s* = 100 %**		**0 < *s* £ 100 %**
10. control costs *c*(*s*) of output observation	***c*(*s*) = 0**		***c*(*s*) > 0**
11. number of agents	**one**		**two or more**
12. traceability *z* of the output	***z* = 100 %**		**0 < *z* £ 100 %**
13. possible range of values for wage *w*	**-¥ £ *w* £ ¥**		**$-x_{low}$ £ *w* £ x_{up} or *w* ³ 0**
14. side of asymmetric information	**one-sided (principal only)**		**double- or many-sided**
15. measurement error of the output	**nonexistent**		**existent**

Source: own representation

5. In contrast to conventional PA-models we assume a reservation utility $m = 0$. This matches a situation where there are binding rules on how certain activities are to be carried through; that is to say, if upstream sellers (agents) do not officially participate, they do not have the choice to produce a lower quality category and sell it at a lower price, but have to refrain from production altogether.

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[2] A formal solution to the continuous problem formulation regularly requires additional assumptions. One example is the LEN-model which restricts the solution to a linear wage or remuneration function and assumes exponential utility functions and normally distributed outputs (cf. WAGENHOFER and EWERT, 1993).

[3] FUDENBERG and TIROLE (1990) call this „three-step procedure“ and divide the minimisation problem into two sub-steps: (i) definition of possible effort levels and their corresponding sets of contracts which induce the agent to choose a certain level; (ii) identification of the least costly contract for each effort level.

[4] Often, the principal has to deal with more than one agent. For more information on multiple agent models cf. e.g. FUDENBERG and TIROLE (1991) or DEMSKI and SAPPINGTON (1984).

[5] For more information on multiple, imperfect estimators (or: performance measures) for the actions of the agent(s) cf. e.g. MILGROM and ROBERTS (1992: 219f.) or HOLMSTRÖM (1979).

6. Conventional PA-models consider a principal who maximises his utility. With only two actions and levels of effort available to the agent, we assume that the principal knows a priori that his maximum utility will result from the higher effort level. He, therefore, only needs to minimise the costs of the incentive and control system which induces the agent to voluntarily comply with specified regulations.

7. Like most PA-models, we assume a stochastic relationship between the agent's effort and the output. We can significantly reduce the complexity of the model if it is reasonable to assume deterministic relationships. In case of full traceability (see 12.), output monitoring is then equivalent with observing the agent's actions directly (cf. RASMUSEN, 1994: 169ff.; ARROW, 1991: 45).

8./9./10. Conventional PA-models assume that the output is observed without costs. In contrast to that, we account for the very characteristics of the food risk problem (i.e. hidden product properties) by considering a limited and costly observability of the output. With food risk problems, full observation is, in fact, either impossible (e.g. because the product will be destroyed by the test) or prohibitively costly. This is why we have to concentrate on random controls of a certain intensity s ($0 < s \le 100$ %). Random controls, however, only provide incomplete information about the output. Given the inevitable use of such an incomplete performance measure, the design of an optimal (first best) incentive and control system is a challenge even though we assume risk neutral agents (cf. HARRIS and RAVIV, 1978).

11./12. The standard PA-model (1) to (3) does not account for multiple agent settings. Design problems resulting from incomplete output information will be aggravated if identified properties cannot be retraced to single upstream sellers. Such multiple agent settings are frequently found in food chains. We account for this problem in the "Specific Food Risk Model" by additionally considering a limited traceability coefficient z ($0 < z \le 100$ %).

13. According to the standard formulation of the PA-model used in chapter 2, we assume at first an unlimited range of values for wages (or: remunerations) w ($-\infty \le w \le \infty$). Like many other PA-applications, however, we will also study the effects of limitations concerning admissible or viable wages, such as restrictions to strictly positive values ($w \ge 0$).

4. The reduced or basic PA-model

In this chapter, we strip the conventional PA-model, step by step, to the bones in order to derive a "Basic PA-Model" which, in turn, serves as starting point for the specification of an adequate "Specific Food Risk Model" in chapter 5.

4.1 A risk-neutral principal in a discrete world

Data for continuous models can hardly be obtained. Therefore, we simplify the model used in chapter 2 and assume that variables such as output, effort, wage etc. are discrete instead of continuous variables. Using the model of KREPS, (1990: 577ff.) we additionally assume a risk-neutral principal. The underlying assumptions may be summed up as follows:

- A risk-neutral principal offers to a risk-averse agent a labour contract specifying a wage w contingent on the output y: $w = w(y)$.
- The agent has a choice of actions from a set $A = \{a_1, a_2, \dots, a_N\}$. Each action a_n causes a deterministic effort k_n to the agent ($k_1 < k_2 < \dots < k_N$).
- The principal can observe different outputs from a set $Y = \{y_1, y_2, \dots, y_M\}$. For each output y_m he specifies a wage w_m. Output is an imperfect signal of the agent's effort, i.e. a function $y = y(k,q)$, both of the agent's effort k and a stochastic influence q. Therefore, wage is also a stochastic function of effort $w = w(y(k,q))$, i.e. each action a_n resp. effort k_n leads to an expected wage $w(a_n) = w(k_n)$.
- For each action a_n, the probability that output y_m is produced is p_{nm}. The action taken by the agent, however, remains ambiguous to the principal since every output is possible under every action ($p_{nm} > 0$ for all n and m).
- If the agent accepts the contract, his expected utility depends on his wage and his effort $EU = \sum_{m=1}^{M} p_{nm} u(w_m) - k_n$; $u(w_m)$ represents a von Neumann-Morgenstern utility function.
- The expected utility of the risk-neutral principal is equivalent to the expected output $\sum_{m=1}^{M} p_{nm} y_m$ less paid wages $w_{min}(a_n)$.
- If the agent rejects the contract, he will still achieve a reservation utility m. The utility of the principal, in this case, will be zero.

The discrete formulation of the principal's incentive problem stated in (4) and (5) may be now written as follows (cf. KREPS, 1990: 587ff.):

Step 1: Determine the minimum wage costs $w_{min}(a_n)$ for each possible action

$$(6)\quad \underset{w}{Min} \sum_{m=1}^{M} p_{nm} w_m = w_{min}(a_n)$$

$$(7)\quad s.t. \sum_{m=1}^{M} p_{nm} u(w_m) - k_n \ge m$$

$$(8)\quad \sum_{m=1}^{M} p_{nm} u(w_m) - k_n \ge \sum_{m=1}^{M} p_{n'm} u(w_m) - k_{n'}, \quad n' = 1, \dots, N$$

Step 2: Determine the maximum payoff over all actions a_n

$$(9)\quad \underset{a_n}{Max} \left(\sum_{m=1}^{M} p_{nm} y_m - w_{min}(a_n) \right)$$

4.2 A Risk-neutral agent with a reservation utility of zero

Assuming a risk-neutral agent and a reservation utility $m = 0$, the cost minimising principal (6) has to specify wages which meet the following constraints:

$$7')\quad s.t. \sum_{m=1}^{M} p_{nm} w_m - k_n \ge 0$$

$$(8') \qquad \sum_{m=1}^{M} p_{nm} w_m - k_n \geq \sum_{m=1}^{M} p_{n'm} w_m - k_{n'}, \quad n' = 1,\ldots,N$$

With the assumption of a risk neutral agent we know that a first best contract is possible; i.e. "what the principal has [… to do] is to get the agent to internalize the effect of his effort decision. The agent [… then] bears fully the cost of putting in less than a high level of effort" (KREPS, 1990: 583). In other words: no fixed remuneration needs to be paid.

Table 2. Notation for a binary food risk model

w_1	=	$-S$	=	sanction imposed on the agent if the undesired/hazardous quality y_1 is detected
w_2	=	P	=	price paid for the product of the desired quality y_2
k_2-k_1=k_2	=	K	=	agent's cost of compliance with regulations
p_{11}	=	r	=	probability of undesired product quality y_1 in case of action a_1 (i.e. non-compliance)
p_{12}	=	$1-r$	=	probability of desired product quality y_2 in case of action a_1 (i.e. non-compliance)
p_{22}	=	q	=	probability of desired product quality y_2 in case of action a_2 (i.e. compliance): $q > 1-r$
p_{21}	=	$1-q$	=	probability of undesired product quality y_1 in case of action a_2 (i.e. compliance)

Source: own representation

4.3 A binary world

We now assume that only two actions are possible: a_1 (non-compliance) and a_2 (compliance). These two actions correspond with two effort levels $k_1 < k_2$. Two outputs $y_1 < y_2$ are possible and two wages $w_1 = w(y_1) < w_2 = w(y_2)$ are paid. In the case of non-compliance the binomial probabilities for output y_1 and wage w_1 are p_{11} and $p_{12} = 1$-p_{11}; in the case of compliance the probabilities for output y_2 and wage w_2 are p_{22} and $p_{21} = 1$-p_{22}. The problem may consequently be restated as follows:

$$(10) \quad Min\, w(a_2) = Min(p_{21}w_1 + p_{22}w_2) = Min((1-p_{22})w_1 + p_{22}w_2)$$

$$(11) \quad s.t. \;\; w(a_2) - k_2 = p_{21}w_1 + p_{22}w_2 - k_2 = (1-p_{22})w_1 + p_{22}w_2 - k_2 \geq 0$$

$$(12) \quad \begin{aligned} w(a_2) - k_2 - w(a_1) + k_1 &= p_{21}w_1 + p_{22}w_2 - k_2 - p_{11}w_1 - p_{12}w_2 + k_1 \\ &= (1-p_{22})w_1 + p_{22}w_2 - k_2 - p_{11}w_1 - (1-p_{11})w_2 + k_1 \geq 0 \end{aligned}$$

Even with only two possible actions of the agent the principal should determine minimum wages for each action and use (9) to identify the action which causes a greater expected utility. Knowing a priori that he will achieve his maximum utility if the agent complies, he only has to minimise the costs of the incentive system which induces the agent to choose action a_2. Hence, the second step of the optimisation can be omitted and the problem is reduced to the constraint cost minimisation according to (10), (11), (12). In other words: the problem is further simplified since the principal has only to ascertain the existence of either y_1 or y_2. However, he avoids having to evaluate the outputs explicitly.

Table 2 gives a detailed interpretation of the incentive problem when the principal is the buyer of a product whose uncertain qualities y_1 and y_2 depend on the actions of the seller (i.e. agent) and a stochastic influence. Conveniently replacing k_2-k_1 by the costs K of compliance[6], it provides a handier notation for the incentive problem than the one we used before.

In order to emphasize the point that we now switch the perspective from labour contracting to food risks, we consistently use the term "remuneration" instead of "wage" for the flows of money (P and S) between principal and agent which are contingent on the output quality y. Following the new notation the constraint minimisation problem may be restated as follows:

$$(13) \quad Min\, w(a_2) = Min(-(1-q)S + qP) = Min(P - (1-q)(P+S))$$

$$(14) \quad s.t. \;\; w(a_2) - k_2 = -(1-q)S + qP - K = P - (1-q)(P+S) - K \geq 0$$

$$(15) \quad \begin{aligned} w(a_2) - k_2 - w(a_1) &= -(1-q)S + qP - K + rS - (1-r)P \\ &= (q+r-1)(P+S) - K \geq 0 \end{aligned}$$

The "Basic PA-Model" (13) to (15) could be termed "*stochastic binary PA-model with full output observation, risk-neutrality both of the principal and of the agent, and a priori-superiority of compliance*".

5. The specific food risk model

In this chapter we account for the specific characteristics of the food risk problem. After considering partial output observation as well as limited traceability in section 5.1, we give an overview of model variants resulting from different stochastic influences in section 5.2. Section 5.3 describes how optimal remuneration formulas in terms of prices and sanctions are to be computed. After accounting for exogenous restrictions concerning sanctions and prices in section 5.4, and for costs of control and reduced damage costs in section 5.5, we call the model "Specific Food Risk Model".

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[6] It is unrealistic to assume that the agent can produce the undesired quality at cost $k_1 = 0$. For the sake of simplicity, we normalise k_1 to zero and avoid having to carry an extra variable through the analysis without impeding the general insights into the structure of the problem solution. A subsequent consideration of k_1 0 in practical model applications will be easy.

5.1 Partial output observation and limited traceability

Prohibitively high costs of full output observation force the principal to resort to random controls. Control intensities $s < 1$ lead to incomplete information about the output (i.e. product quality). In a stochastic world, partial output observation will not only change the expected remuneration for non-compliance $w(a_1)$, but also the expected remuneration for compliance $w(a_2)$. This is due to the fact that, independent of the agent's action or the product quality, the principal will have to pay P whenever the quality is not ascertained. At the same time, the agent can only be made to pay a sanction S if the undesired quality y_1 is evident. Hence, contrary to the case of full observation where output probabilities coincide with remuneration probabilities, partial observation entails remuneration probabilities according to table 3:

Table 3. Remuneration probabilities in the case of partial output observation

	full observation (s = 1)		partial observation (s < 1)	
	remuneration probabilities for ...		remuneration probabilities for …	
	w_1 = -S	$w_2 = P$	w_1 = -S	$w_2 = P$
a_1 = non-compliance (low effort)	r	$1-r$	sr	$(1-s)+s(1-r)$
a_2 = compliance (high effort)	$1-q$	q	$s(1-q)$	$(1-s)+sq$

Source: own representation

Besides the partial observation problem, we have to deal with the limited traceability problem caused by the fact that the detection of an undesired product quality will not always enable the principal to trace the responsible seller. If the identification of the seller is not possible, the latter cannot be made to pay a sanction S. What's more, he can rejoice in the price P which he has already received. The limited traceability complication arises in situations with multiple agents. If we consider both a control intensity $s < 1$ and a limited traceability $z < 1$, the intensity s is to be replaced by the product sz in the probabilities of remunerations-formulation in the right hand side of table 3. Consequently, the incentive problem is to be restated:

$$(16)\quad Min\, w(a_2) = Min\big(P - sz(1-q)(P+S)\big)$$

$$(17)\quad s.t.\ \ w(a_2) - k_2 = P - sz(1-q)(P+S) - K \geq 0$$

$$(18)\qquad w(a_2) - k_2 - w(a_1) = sz(q+r-1)(P+S) - K \geq 0$$

$$0 < sz \leq 1$$

(16) to (18) represent the essential structure of the food risk model we are going to specify. However, restrictions concerning remuneration levels as well as costs of control will still have to be accounted for. The model described so far could be termed *„stochastic binary PA-model with partial output observation, limited traceability, risk-neutrality both of the principal and of the agents, and a priori-superiority of compliance"*.

The binary model developed above has a significant potential for practical applications due to the fact that only few parameters have to be estimated empirically in order to decide on the optimal value of those variables which can be influenced by the decision-maker. Now, the question arises what these decision variables are: in the following sections we will always consider the costs of compliance K and the stochastic relationship between the agents' actions and the outcome (represented by q and r) as given technological parameters. However, we will distinguish different perspectives depending on whether P, S, s, and z need to be considered as given parameters or as decision variables from the designing principal's point of view.

5.2 Stochastic variants of the food risk model

Table 4 provides an overview of model variants resulting from different binomial probabilities q and r as well as different values sz.

Table 4. Variants of the binary model depending on the nature of stochastic influence

		$0 < q < 1$		$q = 1$	
		$sz < 1$	$sz = 1$	$sz < 1$	$sz = 1$
$w(a_1)$	$0 < r < 1$	①a $P-szr(P+S)$	①b $P-r(P+S)$	③a $P-szr(P+S)$	③b $P-r(P+S)$
$w(a_2)$		$P - sz(1-q)(P+S)$	$P - (1-q)(P+S)$	P	P
$w(a_2)-k_2$		$P - sz(1-q)(P+S) -K$	$P - (1-q)(P+S) -K$	$P -K$	$P -K$
$w(a_2)-k_2- w(a_1)$		$\mathbf{sz(q+r-1)(P+S) -K}$	$\mathbf{(q+r-1)(P+S) -K}$	$\mathbf{szr(P+S) -K}$	$\mathbf{r(P+S) -K}$
$w(a_1)$	$r = 1$	②a $P - sz(P+S)$	②b $-S$	④a $P - sz(P+S)$	④b $-S$
$w(a_2)$		$P - sz(1-q)(P+S)$	$P - (1-q)(P+S)$	P	P
$w(a_2)-k_2$		$P - sz(1-q)(P+S) -K$	$P - (1-q)(P+S) -K$	$P -K$	$P -K$
$w(a_2)-k_2- w(a_1)$		$\mathbf{szq(P+S) -K}$	$\mathbf{q(P+S) -K}$	$\mathbf{sz(P+S) -K}$	$\mathbf{(P+S) -K}$

Source: own representation

Different model variants are to be used in different real world situations. Referring to the numbering in table 4 some coherent examples are given below:

Variant ① restates the general stochastic binary PA-model formulation of (16) to (18). It accounts for a stochastic influence whatever the agents' actions may be. It could e.g. be used when infringements of hygienic regulations boost the otherwise low, but nevertheless existing probability of micro-biological contaminations.

Variant ② models situations where compliance does advance, but not guarantee the desired quality, while non-compliance causes the undesired product quality without doubt. An example could be an illegal use of genetically modified organisms (GMO) in food processing. Due to cross-contaminations, there may be incidents of products containing GMO even if the processing agent sticks to rules.

Variant ③ models situations where compliance guarantees the desired quality, while non-compliance may result in both qualities. An example would be an otherwise nonexistent risk of harmful residues in food products if the agent uses prohibited substances in animal feeding.

Variant ④ describes a deterministic situation ($q = r = 1$), such as correct vs. deceiving labelling concerning ingredients. Even though output observation and/or traceability may be only partial, there is a perfect correlation between the agent's action and the output. Hence, the action can be detected with positive probability sz.

There is a particular importance to the most simple model variant ④ due to the fact that this formulation is also relevant in cases where process activities need to be controlled directly. This is relevant in situations where "quality" is defined by the very way of production rather than by analytically verifiable characteristics inherent to the product itself. Setting the traceability coefficient $z = 1$, model variant ④ (observation of deterministic outputs) can be used for situations with direct observation of actions. An application example would be a questionable compliance with specified ecological/social production standards.[7]

Obviously, the different stochastic variants also describe different legal situations and scopes of action available to the principal. Non-ambiguous, observation-based conclusions which make it easy to impose sanctions on non-complying agents can only be drawn in variant ③ and ④. In contrast it will be difficult to penalize an agent in variants ① and ②, because no clear-cut prove for non-compliance can be found by simply observing the product quality.

5.3 Incentive compatible schemes for a given traceability and control intensity

In this section we take a short-time perspective and assume that we have estimations for given parameters K, q, r and sz from our real world situation under examination. We now specify optimal remuneration-formulas in terms of prices and sanctions. Assuming that both constraints of the minimisation problem are binding and treating (17) and (18) as equations, we derive the following formula for P_{min} and S_{min}.

$$(19)\quad P_{min} = K\frac{r}{q+r-1}$$

$$(20)\quad S_{min} = K\frac{1-szr}{sz(q+r-1)}$$

Binding constraints imply agents who are indifferent between participating and not participating as well as between high and low effort levels. In conventional PA-models with risk-averse agents both constraints are binding in the optimal solution (cf. KREPS, 1990: 588). With a risk-neutral agent, the incentive to put in high effort may be increased without increasing the expected remuneration to be paid by the principal. That is to say, we continue to use an equation instead of inequality (17). However, the incentive compatibility constraint (18) does not have to be binding any more. Correspondingly, the levels of S and P may be increased simultaneously according to the following function which we derive by simply converting (17):

$$(21)\quad S(P) = \frac{K-P}{sz(q-1)} - P\text{, with } P \geq P_{min}$$

Table 5 gives a systematic overview of optimal remuneration-formulas. It accounts for different stochastic situations of the binary model and different values sz as described in table 4.

Some of the insights to be gained from this systematic representation of remuneration-formulas are highlighted hereafter, because they are not self-evident, but useful for future applications.

- For given parameters K, q, r and sz, the remuneration-formulas according to table 5 will confine expected remuneration costs exactly to the costs of compliance $w(a_2) = K$, because the participation constraint is always binding. For all (even though very small) values sz there are computable values S which induce compliance at lowest possible costs K.
- The minimum price P_{min} depends only on the parameters K, q, and r, whereas the corresponding minimum sanction S_{min} depends additionally on sz.
- For deterministic outcomes of non-compliance ($r = 1$) and full observation and traceability ($sz = 1$), there is no need for a sanction ($S_{min} = 0$).
- For deterministic outcomes of compliance ($q = 1$), P should not exceed $P_{min} = K$, whereas S may reach infinity[8] in the minimum remuneration cost solution. For $q = r = sz = 1$ the sanction S may reach any value between zero and infinity.
- Higher values than P_{min} and S_{min} according to (21) represent minimum remuneration cost solutions whenever $q < 1$ because the effect of an increase of P is exactly counter-balanced by an increase of S. This does not call for r and permits to increase the incentives for compliance without having to estimate r exactly.

Table 6 clarifies the latter point and presents optimal remuneration-formulas for an exemplary parameter setting: $K = 100$, $q = 0.8$, $r = 0.3$. In this demonstration setting not only the combination of a minimum price $P_{min} = 300$ and a minimum sanction $S_{min} = 700$, but also other combinations such as 400 / 1100, or 500 / 1500 etc. represent minimum cost remuneration-formulas.

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[7] Hence, variant ④a allows e.g. for a quick answer to the question how environmental protection programmes calling for implementation of ecologically sound activities should be designed. Referring to a problem described by HANF (1993), we assume that, given budget restrictions, too many farmers apply for participation. At the same time, random controls of activities ($s < 1$) reveal that (many) farmers break the rules. Given costs of control increasing in s, we can deduce offhand that cost minimising authorities should increase S, but not P or s.

[8] This effect can be used to design "boiling-in-oil-contracts" (cf. RASMUSEN, 1994: 180): very high sanctions or penalties inflicted for outputs which show without doubt that the agent is not complying achieve a first-best solution even for risk-averse agents because complying agents have nothing to fear.

Table 5. Optimal remuneration-formulas in variants of the binary stochastic model

		$0 < q < 1$		$q = 1$	
		$sz < 1$	$sz = 1$	$sz < 1$	$sz = 1$
P_{min} (19)	$0 < r < 1$	①**a** $K\frac{r}{q+r-1}$	①**b** $K\frac{r}{q+r-1}$	③**a** K *	③**b** K *
S_{min} (20)		$K\frac{1-szr}{sz(q+r-1)}$	$K\frac{1-r}{(q+r-1)}$	$K\frac{1-szr}{szr}$	$K\frac{1-r}{r}$
$S = S(P)$ (21), with $P \geq P_{min}$		$\frac{K-P}{sz(q-1)} - P$	$\frac{K-P}{q-1} - P$	$S \geq K\frac{1-szr}{szr}$ *	$S \geq K\frac{1-r}{r}$ *
P_{min} (19)	$r = 1$	②**a** $K\frac{1}{q}$	②**b** $K\frac{1}{q}$	④**a** K *	④**b** K *
S_{min} (20)		$K\frac{1-sz}{szq}$	0	$K\frac{1-sz}{sz}$	0
$S = S(P)$, with $P \geq P_{min}$ (21)		$\frac{K-P}{sz(q-1)} - P$	$\frac{K-P}{q-1} - P$	$S \geq K\frac{1-sz}{sz}$ *	$S \geq 0$ *

* With $q = 1$, choosing $P > P_{min}$ will increase remuneration costs even in cases of sanctions $S > S_{min}$. Furthermore, S may be chosen above the given limit independent of P.

Source: own representation

Table 6. Optimal combinations of prices *P* and sanctions *S* in the case of a risk-neutral agent in a demonstration setting: $K = 100$, $q = 0.8$, $r = 0.3$

P	$S(P) = \frac{K-P}{sz(q-1)} - P$ (21)		participation constraint (17) $P - sz(1-q)(P+S) - K$	incentive compatibility constraint (18) $sz(q+r-1)(P+S) - K$	expected remuneration cost (16) $P - sz(1-q)(P+S)$
	$sz = 1$	$sz = 0.1$			
300	700	9 700	0	0	100
400	1 100	14 600	0	50	100
500	1 500	19 500	0	100	100
…	…	…	…	…	…

Source: own demonstration example

It should be emphasised that the approach taken so far represents indeed a somewhat simplistic and very short-term perspective: on the one hand, it assumes that both prices and sanctions can be adjusted by a single decision-making principal (which in practice is often not the case). On the other hand, it assumes that both the control intensity s and the traceability z cannot be changed.

5.4 Incentive compatible schemes for a given traceability and given restrictions concerning the remuneration

Upper limit of the sanction

So far we used K, q r, z and s as given model parameters and derived optimal contracts in terms of optimal combinations of prices and sanctions, one of them being P_{min} and S_{min}. Now we take a different perspective: we assume that we have estimations for given parameters K, q, r, z and a predefined upper limit[9] of the sanction S_{up}. Consequently, we now specify optimal remuneration-formulas in terms of prices and control intensities. The minimum control intensity s_{min} which is to be combined with P_{min} is derived by converting (20):

$$(22) \quad s_{min} = \min\left(\frac{K}{z(S_{up}(q+r-1)+Kr)};\quad 1 \right)$$

All parameter constellations leading to computed values $s_{min} \leq 1$ according to the first term in (22) allow for a minimum remuneration cost solution in terms of a combination of P_{min} and s_{min} which induces compliance[10] at costs K.

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[9] As a rule, S cannot be chosen freely in real world situations. On the one hand, this might be due to legal restrictions concerning the admissible sanction level. On the other hand, there is an arguable upper sanction limit which an individual can be made to "feel". Exceeding this limit will presumably not be effective. Referring to the exemplary setting of table 6, we would e.g. compute a sanction $S_{min} = 10^{12}$-300 in case of $sz = 10^{-9}$. It is obviously doubtful whether such an incentive system would work.

[10] Ignoring costs of control we are even free to choose higher control intensities s $(1 \geq s \geq s_{min})$. This, in turn, allows us to determine a minimum sanction according to (20), which is lower than the predefined sanction limit.

However, all constellations where the first part of (22) yields values greater than unity prevent the minimum remuneration cost solution. Wording the facts more generally, we can state that all limits S_{up} which force the first term in (22) to be greater than a predefined control intensity increase the remuneration costs. If the principal wants to induce compliance under such circumstances he needs to ensure that the incentive compatibility constraint is met. After equating (18) with zero and after a simple conversion of the equation, we are able to determine the necessary price P which induces the agent to comply:

$$(23)\quad P=\begin{cases}\dfrac{K}{sz(q+r-1)}-S_{up}, & \text{if } 1\geq s<\dfrac{K}{z(S_{up}(q+r-1)+Kr)} \qquad (a)\\[2ex] \dfrac{K}{sz(q+r-1)}-S_{up}=P_{min}=K\dfrac{r}{q+r-1}, & \text{if } 1\geq s\geq\dfrac{K}{z(S_{up}(q+r-1)+Kr)} \qquad (b)\end{cases}$$

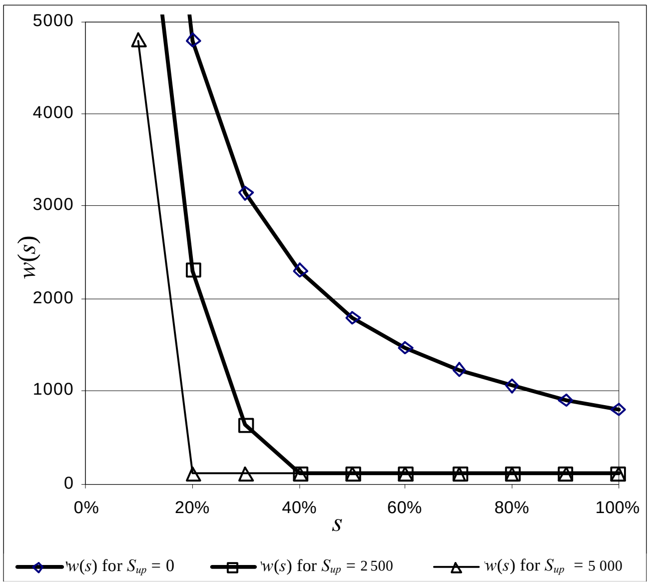
(23) demonstrates that, with given sanction limits, expected remuneration costs of the cheapest contract which induces compliance do not simply come up to K, but become a function $w(s)$ of the control intensity. Resorting to (16) we know that remuneration costs for compliance $w(a_2)$ are to be computed as follows:

$$(24)\quad w(a_2)=P-sz(1-q)(P+S)$$

Using (23) we know, that, for a given S_{up}, the price P, which meets the incentive compatibility constraint, depends on the intensity s. Consequently, we substitute (23) into (24), use $w(s)$ instead of $w(a_2)$ and derive the following remuneration function depending on s:

$$(25)\quad w(s)=\begin{cases}\dfrac{K}{sz(q+r-1)}-S_{up}-\dfrac{(1-q)K}{q+r-1}, & \text{if } 1\geq s<\dfrac{K}{z(S_{up}(q+r-1)+Kr)} \qquad (a)\\[2ex] K, & \text{if } 1\geq s\geq\dfrac{K}{z(S_{up}(q+r-1)+Kr)} \qquad (b)\end{cases}$$

Figure 1. Remuneration functions depending on the control intensity *s* for different upper limits S_{up} (K = 100, q = 0.8, r = 0.3, z = 1)



Source: own demonstration example

Figure 1 illustrates the nature of the remuneration function as a whole by referring again to the demonstration setting of table 6. Additionally, we distinguish three different upper limits of the admissible sanction. With the severe limit $S_{up} = 0$, there is no intensity s which allows for the minimum remuneration cost solution $w(s) = K = 100$, but the expected remuneration has to be computed according to (25a) on $0 < s \leq 1$. With less severe limitations, such as $S_{up} = 2\,500$ or $S_{up} = 5\,000$, there are minimum control intensities s_{min} above which the minimum remuneration costs $w(s) = 100$ can be obtained.

Table 7 clarifies the point by giving some results for $S_{up} = 0$. Still assuming a traceability $z = 1$, the principal will have to pay a price $P = 1\,000$ (2 000, 5000) in the case of given control intensities $s = 1$ (0.5, 0.2) in order to induce the agent to comply with rules. This coincides with expected remuneration costs of 800 (1 800, 4 800), compared to costs of 100 without limitations of S. These figures demonstrate that, independent of sz, remuneration costs $w(s)$ are by (1-q)K/(q+r-1) lower than the required price P.

If the principal of our demonstration example pays prices P which are lower than the indicated values, profit maximising agents will simply consider them as windfall profits and not comply because the incentive compatibility constraint is not met. Although we have so far argued with a given traceability $z = 1$, table 7 demonstrates that upper limits of S are especially costly for the principal in cases of a low *product sz*. This in turn may be caused by high costs of control resulting in a low control intensity s in the optimal solution (see section 5.5), or by a low traceability z inherent to the very structure of the food chain under examination (see chapter 6).

Upper limit of the sanction and a given market price

Public authorities wishing to induce compliance with legal rules often have to deal with situations where there is a given market price and a maximum level of sanction at the same time. That is to say we now take the perspective that K, q, r, z, S_{up} and P are given parameters. In such a situation, the only tool available to authorities on the short run is the adjustment of the control intensity. After setting $S = S_{up}$ and converting (18) we get the control intensity which needs to be applied:

$$(26)\quad s=\min\left(\frac{K}{z(q+r-1)(P+S_{up})};\quad 1\right)$$

If we assume that P meets P_{min} in the market place, then (26) is equivalent to (22).[11] It is of great practical rele-

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[11] In cases q 1, there is a range of s defined by (17) and (18) which meets the participation and incentive compatibility constraint for given prices P P_{min}. In non-ambiguous cases $q = 1$, however, any intensity exceeding (26) can be chosen because complying agents will not be affected (cf. footnote 8).

Table 7. The effects of upper limits for S and s on remuneration costs for the demonstration setting: $K = 100$, $q = 0.8$, $r = 0.3$, $z = 1$

	S_{up}	$P = \frac{K}{sz(q+r-1)} - S_{up}$ (23)	participation constraint (17) $P - sz(1-q)(P+S_{up}) - K$	incentive compatibility constraint (18) $sz(q+r-1)(P+S_{up}) - K$	expected remuneration costs (24)=(25) $P - sz(1-q)(P+S_{up})$
$sz = 1$	0	1 000	700	0	800
$sz = 0.5$	0	2 000	1 700	0	1 800
$sz = 0.2$	0	5 000	4 700	0	4 800

Source: own demonstration example

vance that there is a level of S_{up} which prevents a solution to the incentive problem altogether because no $s \leq 1$ according to the first term in (26) can be found. After setting $s = 1$ and converting (18), we know that this is the case if the following condition applies:

$$(27) \quad S_{up} < \frac{K}{z(q+r-1)} - P$$

Assuming again that P equals P_{min} in the market place, (27) is equivalent to $S_{up} < S_{min}$, the latter being computed for $s = 1$ according to (20). It is important to emphasize that, if neither P nor S can be influenced, and if (27) applies, the only hope for a solution to the incentive problem is to change the inherent structure of the food chain and increase z. This, however, also has limitations, because z cannot exceed unity. In our continuously used demonstration example we would e.g. need a minimum sanction $S = 700$. Otherwise there is no way to induce compliance even in the case of full traceability and a control intensity of 100%. Adverse selection will be the consequence (cf. chapter 6).

5.5 Incentive compatible schemes accounting for costs of control and reduced damages

Direct costs of control

We now account for costs of control which we have ignored so far. Instead of reducing the problem to the minimisation of remuneration costs, we now minimise the costs of the incentive and control system as a whole. That is to say, our perspective is that we have given parameters K, q, r, z, S_{up}, and a cost of control function $c(s)$ increasing in the intensity s. Again, the optimal control intensity and price need to be determined. We know that the total costs (TC) of the incentive and control system as a whole are given by:

$$(28) \quad TC = w(s) + c(s)$$

The remuneration function (25) is strictly decreasing in s on $s < \frac{K}{z(S_{up}(q+r-1)+Kr)}$ and constant on $s \geq \frac{K}{z(S_{up}(q+r-1)+Kr)}$, with s limited to the range $0 < s \leq 1$. In contrast, the cost of control function $c(s)$ is strictly increasing in s. Assuming a linear cost of control function $c(s) = Cs$ (where $C = dc/ds$ are the costs of full observation), and after differentiating (25a) we know that an intensity $\hat{s}$ which meets the following equation

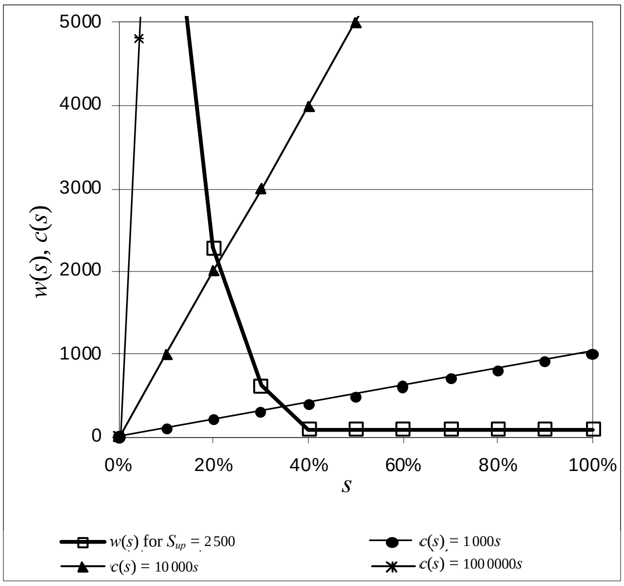
$$(29) \quad \frac{dw}{ds} = \frac{1}{\hat{s}^2}\frac{-K}{z(q+r-1)} = -\frac{dc}{ds} = -C \qquad \Rightarrow \hat{s} = \sqrt{\frac{K}{z(q+r-1)C}}$$

on the decreasing part of the remuneration function (25a) represents a solution to the cost minimisation problem. However, in some circumstances there is no solution $\hat{s}$ on the decreasing part of the remuneration function. In this case, the optimal solution is simply given by s_{min} according to (22). Therefore, a general formulation for the optimal control intensity s_{opt} is:

$$(30) \quad s_{opt} = \min(\hat{s};\, s_{min})$$

Of course, P has to be computed simultaneously according to (23) if compliance is to be induced. Figure 2 illustrates the facts for our familiar demonstration setting. On the one hand, it shows the cheapest remuneration function for a given upper limit $S_{up} = 2\,500$. On the other hand, it depicts different linear cost of control functions.

Figure 2. Remuneration and cost of control functions depending on s ($K = 100$, $q = 0.8$, $r = 0.3$, $z = 1$)



Source: own demonstration example

Table 8. Optimal control intensities for different control costs and different upper limits S_{up} ($K = 100$, $q = 0.8$, $r = 0.3$, $z = 1$)

cost function $c(s)$	$\hat{s}$ according to (29)	s_{min} according to (22) for upper sanction levels …			optimal control intensity s_{opt} according to (30) for …		
		$S_{up} = 0$	$S_{up} = 2500$	$S_{up} = 5000$	$S_{up} = 0$	$S_{up} = 2500$	$S_{up} = 5000$
$1000s$	1.00	min(3.33; 1)	min(0.36; 1)	min(0.19; 1)	1.00	0.36	0.19
$10000s$	0.32				0.32	0.32	0.19
$100000s$	0.10				0.10	0.10	0.10

Source: own demonstration example

Table 8 depicts different optimal control intensities for different linear cost functions and different upper sanction levels.

(29) reveals the fact that the gradient of the remuneration function dw/ds does not depend on S_{up}. Correspondingly, the intensity $\hat{s}$ only depends on the parameters K, q, r and z on the one hand and on the gradient of the cost of control function $C = dc/ds$ on the other hand. The optimal intensity s_{opt}, however, does depend on S_{up}, because the latter determines s_{min}. With less severe upper sanction limits, the range of the control intensity, on which minimum remuneration cost solutions $w(s) = K$ are possible, increases. In other words: differentiation according to (29) is only relevant if high gradients dc/ds coincide with severe limits S_{up}. Otherwise, s_{min} represents the minimum cost solution for the incentive and control system as a whole.

Net costs of control after consideration of reduced damage costs

Let us now realistically consider that any unidentified product carrying the undesired quality y_1 causes a damage $D = y_2 \text{-} y_1$ to the buyer or principal. If the incentive compatibility constraint is met, the resulting net cost of control function of the principal may be written as follows:

$$(31)\quad c_{net}(s) = c(s) - D(1-q)s$$

The net total costs (TC_{net}) of the incentive and control system as a whole are now given by:

$$(32)\quad TC_{net} = w(s) + c_{net}(s)$$

Figure 3 illustrates different types of net cost of control functions $c_{net}(s)$. Contrary to the isolated cost of control function $c(s)$, they may be either strictly increasing (see type ①), or strictly decreasing (see type ②), or have a minimum or maximum (see type ③ and ④). The type of $c_{net}(s)$ depends on the curvature of $c(s)$ and the gradient of the reduced damage costs $D(1\text{-}q)$.

We now have to compute optimal control intensities accounting for different types of net cost of control functions. However, we do not execute formal solutions for various non-linear cost of control functions (be they due to reduced damage costs or other reasons) in this paper. This just requires explicitly deriving the minimum of TC_{net} on $0 < s \quad 1$, instead of simply using the first derivation as we do in the particular case of linear cost functions. Two interesting situations are to be emphasised in this context:

- Contrary to the isolated costs of control, the net cost of control function $c_{net}(s)$ might even be strictly decreasing in some cases; a negative gradient implies that, independent of the incentive problem, an intensity $s = 1$ is optimal because an increase of control costs is always justified by reduced damage costs.
- With a positive gradient of the net cost of control function and with no moral hazard involved (i.e. agents do not have the choice of non-compliance), the solution to the optimal intensity problem is quite trivial: no controls should be made because increased costs of control always exceed reduced damages (cf. LIPPERT, 2002).

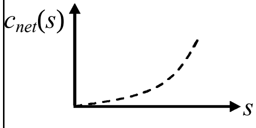
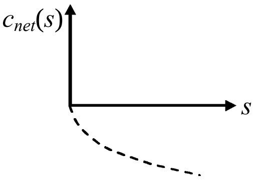
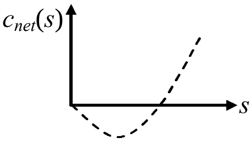
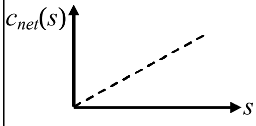
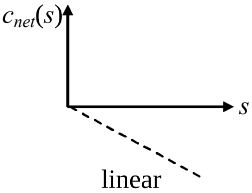
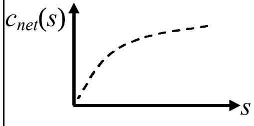
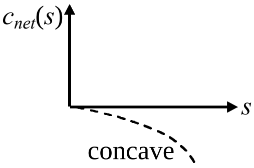
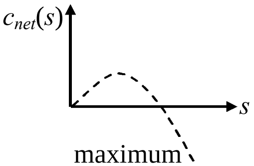
Optimal control intensities accounting for the actual type of cost of control function together with (23) still represent solutions for the *"stochastic binary PA-model with partial output observation, limited traceability, risk-neutrality both of the principal and of the agents, and a priori-superiority of compliance"*. It is now extended to the more realistic "Specific Food Risk Model". On the one hand, it has the capacity to account for the determinants of the remuneration function, i.e. the costs of compliance K, the stochastic relationship between the agents' actions and the output (expressed by q and r), the traceability z, and an eventual upper sanction limit S_{up}. On the other hand it is able to consider plausible costs of control and reduced damage cost functions. In short- to medium term practical applications, where the principal is only able to adjust the price and/or the control intensity, this represents the relevant model. In the following section 6 we will see, however, that in some situations structural changes of the value chain will be necessary in order to effectively induce compliance.

6. Considering different structures of food chains and control systems

So far, we have neither considered structural changes of food chains (and therefore different traceability coefficients) nor structural changes of control systems (and therefore different cost of control functions due to different control technologies, organisations and responsibilities). Using the terminology of New Institutional Economics we would say that we have not investigated comparative costs of different institutional schemes, but only the microeconomic level of governance structures (cf. e.g. MENARD, 2001). Although we are not focusing on the question of institutional change in this paper, we comment hereafter on value chain structures which might (i) prevent incentive compatible solutions in some situations altogether or (ii) prevent optimal solutions in others. Often, such structures can only be changed with great difficulty or at high costs.

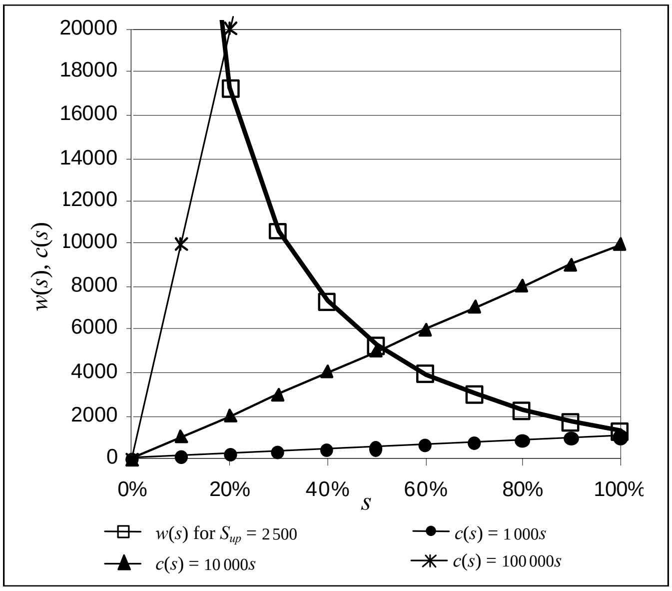
(i) Adverse selection (cf. e.g. AKERLOF, 1970; RASMUSEN, 1994: 224ff.) will arise if the buyer (principal) is not willing to pay the costs of a contract and control system which

Figure 3. Typology of net cost of control functions $c_{net}(s)$ depending on the curvature of costs of control functions $c(s)$ and gradients of reduced damage costs functions $D(1-q)$

	types of net cost of control functions			
	① $D(1-q) \le dc/ds$ for $0 < s \le 1$	② $D(1-q) \ge dc/ds$ for $0 < s \le 1$	③ $D(1-q) \ge dc/ds$ $\rightarrow D(1-q) \le dc/ds$	④ $D(1-q) \le dc/ds$ $\rightarrow D(1-q) \ge dc/ds$
$c(s)$ = concave	 concave strictly increasing	 convex strictly decreasing	 minimum first decreasing, then increasing	X X X
$c(s)$ = linear	 linear strictly increasing	 linear strictly decreasing	X X X	X X X
$c(s)$ = convex	 convex strictly increasing	 concave strictly decreasing	X X X	 maximum first increasing, then decreasing

Source: own representation

Figure 4. Remuneration and cost of control functions depending on s ($K = 100$, $q = 0.8$, $r = 0.3$, $z = 0.25$)



Source: own demonstration example

induces compliance within given system structures. Such a situation is likely to emerge if a relatively low upper sanction limit coincides with a high gradient of the (net) cost of control function and/or a low traceability inherent to the existing structures of the food chain and the control system. If sellers (agents) do not comply, buyers will loose their willingness to pay a (higher) price for the high quality altogether, because non-compliance and low qualities have to be expected anyhow; i.e. the collective advantage of compliance will not be realised. Even if "better" structures are conceivable in a long-term perspective, buyers might be deadlocked in the "wrong" situation because, within the given institutional framework, no individual buyer is prepared to pay the investment costs which are needed to change the very structure of the food chain and control system. In other words: besides the external effect problem caused by the microeconomic structure of the transactions between principal and agents (information asymmetry, multiple agents), we are additionally facing an external effect problem due to a multiple principal setting.

(ii) Public authorities acting on behalf of buyers and deciding on control intensities might at least allow for solutions which induce compliance. However, the multiple principal problem may still persist and cause suboptimal solutions. Going back – for the sake of simplicity – to an isolated cost of control function, a coherent example is quickly described: controls organised and financed by public authorities and associated with state imposed sanctions leave only the price to be decided on by buyers. Not bearing the costs of control nor benefiting from sanctions paid by non-complying sellers, buyers will tend to pay lower prices and demand higher control intensities than those resulting according to the optimal solution (23) and (30).

Figure 4 illustrates the situation by referring again to the familiar demonstration setting of figure 2 with an upper sanction limit of 2500, but showing now the effects of a traceability $z = 0.25$. The optimal control intensities for isolated cost of control functions $c(s) = 1000s$ ($10000s$, $100000s$) amount to $s_{opt} = 1$ (0.63, 0.2) according to (30). It seems doubtful whether buyers will be willing to pay respective prices $P = 1500$ (3825, 17500) according to (23). Lower prices, however, will require non-optimal control intensities s > s_{opt}.

Table 9. The effects of traceability on optimal control intensities and required prices ($K = 100$, $q = 0.8$, $r = 0.3$; $S_{up} = 2500$)

	$c(s) = 1000s$		$c(s) = 10000s$		$c(s) = 100000s$	
	s_{opt} (30)	P (23)	s_{opt} (30)	P (23)	s_{opt} (30)	P (23)
$z = 0.25$	1	1500	0.63	3825	0.2	17500
$z = 1$	0.36	300	0.32	662	0.1	7500

Source: own demonstration example

Table 9 emphasises the effects of traceability by comparing the prices P which are required to induce compliance in the optimal solution in the case of $z = 0.25$ and $z = 1$. Including received sanctions the expected remuneration costs according to (25) just falls 200 below the indicated prices P. This demonstrates that changing system structures and therefore z might allow for a lower cost solution to the incentive problem, especially if changing the system brings forth a higher traceability and lower costs of control at the same time. Effects would even be more pronounced if higher sanctions could also be enforced in the new system. However, costs of change have to be considered in the comparison. Hence, beyond simply optimising incentives and controls within a given framework, taking the long-term perspective implies thinking about systems innovations in terms of investments in new structures. To effectively do so, we have to answer the following questions:

- Is it viable and economically efficient to change the essential mode of transactions in the food chain at given investment costs in order to increase the traceability and eventually decrease the costs for an incentive compatible system in the future?
- Is it viable and economically efficient to develop better control technologies and/or can higher sanctions be enforced, allowing for a regime of contract and control which induces compliance at lower costs?
- Is there a more efficient structure of the control system which solves the multiple principal problem in terms of internalising both benefits and costs of the incentive and control system? In other words: what is the best organisation of a reliable control system? Who should be responsible for such a system? Who should pay for it and who should get the benefits in terms of received sanctions?

Taking up our model perspective also supports the understanding and interpretation of empirical findings concerning dynamic changes of system structures. We could, for instance, rationalize the recent activities of the food industry in Germany, which introduced an integrative quality management system “QS Fleisch” (quality safeguard meat): this move towards a vertically integrated system which all actors in the food chain are free to participate in, may be considered as a change of system structures and a changeover from public to private control. In theoretical terms, but also according to the statements of the industry, the objectives of such a vertical integration are as follows:

1. A compulsory self-documentation of individual activities on every level of the food chain is supposed to generate valuable information which helps to improve operational processes. Consequently, complying agents should be able to increase the probability q of the desired high product quality and/or lower the compliance costs K.
2. A system of independent controls which resort to the compulsory self-documentation of individual activities and to systematically shelved specimens is supposed to increase the traceability z, lower the costs of control $c(s)$ and allow for higher control intensities s.
3. The new system of transactions and control is supposed to inspire confidence to consumers and increase the value added within the food chain because higher prices can be obtained. Realised prices combined with sanctions, which penalise dysfunctional behaviour, are supposed to induce compliance on all levels of the new system.

Obviously, the outlay of the quality management system “QS Fleisch” tackles the serious control and traceability problems of the previous system which have become evident over the last decades. However, like any other system, it should and could be systematically analysed in regard to its incentive compatibility and costs compared to other institutional schemes.[12]

7. Outlook

Luckily, we do not have to assume that all food chain actors infringe regulations if they have economic reasons to do so. Some agents may comply because of moral reasons (individual preferences). Analyzing and influencing individual preferences beyond the profit maximising objective, however, is not within the scope of a microeconomic approach. Hence, for a more complete understanding of what it is exactly that makes people break (or not break) rules in the food supply chains, applied social studies would be additionally needed. But even without that completion, the microeconomic food risk model specified in this paper is valuable because we can plausibly assume that the probability of non-compliance varies in accordance with the economic cost/benefit-ratio of rule-breaking behaviour (cf. LIPPERT, 1997).

The model developed so far enhances our understanding of moral hazard in food chains by showing the economic effects of variations of variables such as compliance costs, stochastic influences, control costs etc. Because of its manageable data requirements, it is a ready to use model. However, for practical application empirical data will have to be procured. Furthermore, one has to bear in mind that a static perspective will not suffice for real world problems which regularly represent repeated games requiring a dynamic

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[12] With regard to the discussion „public/private control“ and „optimal degree of vertical integration“ in the agribusiness cf. e.g. BECKER (2000), KÜHL (1999), SCHRAMM and SPILLER (2002), VETTER and KARANTINIS (2001).

approach. In order to meet the requirements of multi-period problems, we will have to compute prices and sanctions as capitalised future payment flows.

Of course, a re-extension of the food risk model with regard to the restrictive assumptions which were made may be sensible in some cases. The following extensions seem to be promising in certain situations:

- Instead of considering compliance vs. non-compliance, finer partitions of the agents' scope of action such as different degrees of compliance could be accounted for in generally discrete model formulations.
- Instead of considering one set of outputs both for compliance and for non-compliance, different sets or even probability distributions for continuous output values could be accounted for. This is especially valuable if outputs can be identified which reveal the agent's action without doubt allowing for "boiling-in-oil-contracts" (cf. RASMUSEN, 1994: 180).
- Instead of minimising costs, the value (damage) of the desired (undesired) product quality to the principal could be explicitly considered in utility maximising models. This is even an obligatory procedure if we are comparing different system structures leading to different stochastic relationships between the agents' actions and the output.
- Instead of assuming risk-neutral actors, the implications of risk aversion on optimal solutions (or at least the direction of change caused by risk aversion) could be shown.
- Instead of assuming homogeneous agents with identical costs of compliance, heterogeneous agents could be modelled. This would enable us to appraise both the percentage of participating and the percentage of complying agents under a certain design.
- Instead of assuming a non-ambiguous observation of the output, a statistical measurement error rate could be estimated which would allow for an appraisal of first and second degree errors and their implications on optimal contractual designs.

However, before increasing the complexity of applied models, it should always be checked whether the required data can be obtained with available resources, and whether informational gains justify additional costs.

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