Int. J. Production Economics 177 (2016) 149–162

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Traceability and reputation in supply chains

Alexander E. Saak

Research Fellow, Markets, Trade, and Institutions Division, International Food Policy Research Institute, 2033 K Street, NW, Washington, DC 20006-1002, USA

A R T I C L E I N F O

Article history:
Received 29 April 2015
Received in revised form
24 March 2016
Accepted 15 April 2016
Available online 16 April 2016

Keywords:
Supply chain
Traceability
Reputation
Moral hazard
Imperfect monitoring

A B S T R A C T

The paper studies the questions of why and when a supply chain should invest in a traceability system that allows the identification of which supplier is responsible for quality defects due to insufficient non-contractible effort. We consider an environment with complementarity in upstream and downstream efforts to provide quality, imperfect, lagged signals of intermediate and final quality, and repeated interaction. It is demonstrated that in deciding whether to maintain information about product origin, firms face a trade-off. On one hand, the downstream firm is tempted to condone limited upstream shirking when products are not traceable to their firm of origin. On the other hand, the downstream firm is tempted to vertically coordinate shirking in the provision of quality when products are traceable. Perfect traceability is not optimal if (1) the ratio of the cost savings from upstream and downstream shirking is neither too high nor too low or (2) the downstream firm sufficiently infrequently detects input defects or (3) the consumer experience is a sufficiently noisy signal of quality.

1. Introduction

In 2002, the European Union adopted legislation requiring all food to be traceable to its origins of production, and the United States and several other countries are considering the adoption of similar legislation (European Union, 2002; Food and Drug Administration, 2012). The rationale for mandatory traceability is that it enables timely identification of the source of contamination or defects in supply chains where inputs from different suppliers are commingled during the processing stage (Roth et al., 2008; Trienekens and Zuurbier, 2008). Traceability can also be seen as a tool to maintain trust within a supply chain and build a reputation for producing high quality products when firms' behavior is not perfectly observed by consumers (Marucheck et al., 2011). As discussed in Golan et al. (2004), traceability systems in agro-food industries collect information about the origin of the inputs and the processing history, and vary in the number of product attributes (breadth) and production stages (depth) covered by the system as well as the accuracy of information about product movement and origin. Charlier and Valceschini (2008) pointed out that informational requirements under mandatory traceability may not be sufficiently stringent to allow a complete tracing of a given unit of a final product to its suppliers of origin. Here we study the decision to adopt a traceability system that provides information about product movement in the presence of moral hazard at the upstream and downstream stages of production and reputational effects.

We consider a two-stage supply chain with *anonymous*, *vertically complementary*, *experience* inputs such that (a) the identity of the upstream supplier of a given product is unknown, (b) the final quality is low if quality at any stage of production is low, and (c) both intermediate and final product qualities are unverifiable and imperfectly observed after consumption (Buhr, 2003; Gibbons, 2005; Skilton and Robinson, 2009).[1] For example, in meat supply chains processors source live animals from multiple producers and some quality attributes such as taste and texture are discovered after the identity of supplier has been separated from the meat cut. Meat quality is influenced by on-farm and off-farm practices such as genetic screening and feeding of animals, sanitation, veterinary care, and handling during transportation, slaughter, and storage (Dahl et al., 2004; Koohmaraie et al., 2005). Another example is a fresh produce supply chain where shipments from multiple growers are mixed during post-harvest processing, and quality attributes such as shelf life and internal defects are only revealed over time. High quality produce requires investments in appropriate farming practices by growers and investment in

[1] Upstream and downstream efforts can also be "vertically substitutable" or "horizontally complementary". For example, vertical substitutability arises if an upstream party can exert effort such as sanitation to prevent microbial contamination and a downstream party can exert an effort such as irradiation or pasteurization treatment to reduce it (Roe, 2004). Inputs can be horizontally complementary in determining quality attributes if low quality inputs from one supplier increase the likelihood that the quality of products that originate from other suppliers is also low.

E-mail address: asaak@cgiar.org

http://dx.doi.org/10.1016/j.ijpe.2016.04.008
0925-5273/

continuous temperature control during shipping by distributors (Blackburn, Scudder, 2009; Hardesty and Kusunose, 2009).

To evaluate the value of information about input origin, we combine the static model of quality leadership in a supply chain with complementary inputs of Hennessy et al. (2001) and the dynamic model of firm reputation with imperfect monitoring of Cai and Obara (2009). In the environment studied in this paper, firms along the supply chain will shirk in the provision of quality to save costs unless they are sufficiently patient to build reputation of high quality. As in the case of reputation of a single firm, in our setting with vertically related firms customer trust is maintained in equilibrium because bad performances in the final good market are followed by a punishment phase during which the price is reduced or financial penalties are paid (Bar-Isaac and Tadelis, 2008).[2]

The key feature of our model is that information about input origin has both *positive* and *negative* effects on reputation building. On the one hand, traceability allows to base input payments on *individual* rather than *group* performance. On the other hand, traceability allows matching the levels of upstream and downstream efforts put into products. This makes it possible to *vertically coordinate* downstream and upstream shirking with a subset of suppliers. Whether the adoption of a traceability system is optimal in equilibrium is determined by comparing the strengths of the temptation to engage in vertically coordinated "top down" shirking and the temptation to condone occasional anonymous "bottom up" shirking. We find that perfect traceability is not optimal in a supply chain if one or more of the following conditions hold: (1) the ratio of the cost savings from upstream and downstream shirking is neither too high nor too low, (2) the downstream firm not too often detects input defects, (3) the consumer experience is a sufficiently noisy signal of quality.

If the ratio of the upstream and downstream costs of provision of high quality is either very small or very large, consumers need to punish the downstream firm for bad performance in the final good market less harshly under traceability. This happens because the downstream firm has little to gain from vertically coordinated deviations relative to vertically uncoordinated deviations, but it is able to punish shirkers individually. However, if the cost savings from upstream and downstream shirking on efforts to provide quality are similar, supplier anonymity raises profits because the equilibrium temptation to vertically coordinate shirking is stronger than the temptation to tolerate a few anonymous low quality inputs.

The intuition behind the effect of more precise consumer monitoring of upstream and downstream efforts on the value of traceability is also interesting. When the signals of final quality are imprecise, the supply chain has little reputational capital at stake. As a result, supplier anonymity is optimal because no additional punishment in the final good market is necessary to make the downstream firm's promise to punish all suppliers for anonymous shirking credible. However, if the signal of final quality is precise, good reputation is very valuable. Then the promise to punish all suppliers for occasional anonymous shirking will not be credible without more severe punishments in the final good market than those that are necessary to assure that the downstream firm restrains itself from vertically coordinated shirking.

Most of the previous economics literature on traceability studies the effects of traceability on the choices of efforts to provide safe food.[3] Pouliot and Sumner (2008) show that an exogenous increase in traceability has a positive effect on food safety in a supply chain with farms, marketers, and consumers by increasing liability costs for defective products. In Pouliot and Sumner (2012), farms market food over two periods and traceability enables a targeted removal of unsafe food from the market in the second period. They find that the effects of traceability on the profit-maximizing levels of food safety for individual farms and the industry acting as a group depend on the relative strengths of the quantity and confidence effects of safety failures on demand. Resende-Filho and Hurley (2012) demonstrate that the principal chooses the lowest level of costly traceability precision in a static principal-agent setting with risk neutral agents. In this paper we focus on the decision to adopt a traceability system in an environment where the effects of consumer information about product quality on prices and future demand are derived rather than assumed.[4]

Investment in product quality under formal contractual arrangements between suppliers and manufacturers is studied in operations management literature. Baiman et al. (2000) and Lim (2001) consider contract design in static settings with one supplier and one manufacturer. Baiman et al. (2004) and Li et al. (2011) study quality investments in a supply chain where one manufacturer contracts with multiple suppliers and defective components cause the failure of the whole product (the "weakest-link" property). In their settings, the manufacturer makes a single product and does not observe whether individual components are defective without testing. DeYong and Pun (2015) examine suppliers' dishonest behavior in a multi-tiered supply chain with endogenous investments in production technology and inspections, and show that the buyer can benefit from a high rework cost or when the suppliers' penalties for cheating are low. Here we consider a multi-product environment with the "weakest-link" property and assume that downstream firm privately learns the qualities of intermediate products (whether individual components are defective) after processing has begun and the identity of the supplier has been separated from the product.

More generally, our paper is related to the literature on repeated games with imperfect monitoring concerned with the role of information structures. In particular, Kandori (1992) shows that in repeated games with imperfect public monitoring, the set of equilibrium payoffs expands when signals become more informative. In contrast, in our setting with private inter-firm monitoring of input quality, the set of equilibrium payoffs may expand when signals of product origin are garbled. Fong and Li (2010) show that intertemporal garbling of public signals can increase the efficiency of relational contracting by reducing temptations to renege. We consider garbling of private information about the sources of inputs within periods, which reduces temptations to shirk as well as renege.

[2] Although in equilibrium consumers sometimes punish the downstream firm, they do not make any statistical inferences about the upstream and downstream efforts because there is no shirking on the equilibrium path. Some authors (e.g., Cabral (2009)) use the word "trust" to describe an equilibrium of the repeated game where the public history of the game is encapsulated in the consumers' belief about the firm's trustworthiness.

[3] The effects of traceability are also studied in a model of collective reputation with network monitoring in Saak (2012). While Saak focuses on the role of "horizontal" peer monitoring, we consider a supply chain in which the upstream firms do not observe one another's effort choices and study the effects of traceability on the vertical relationship between upstream and downstream firms. There are many empirical studies of the determinants of adoption and effects of traceability in supply chains (Resende-Filho and Buhr, 2008; Banterle and Stranieri, 2008; Pouliot, 2011; Galliano and Orozco, 2011, Liao et al., 2011, and Heyder et al., 2012).

[4] Charlier and Valceschini (2008) examine the effects of mandatory traceability established under European regulation and the role of coordination and leadership by downstream firms in creating industry-wide incentives to adopt a more stringent traceability system. A model of voluntary adoption of traceability in supply chains with network effects is also studied in Souza-Monteiro and Caswell (2010). Epelbaum and Martinez (2014) consider the impacts of the technological evolution of food traceability systems in a framework based on the Resource Based View of the firm. Dai et al. (2015) propose a design method for supply chain traceability systems that minimizes system-wide costs and takes into account participation incentives of individual chain parties.