

II. Efficient Traceability Systems Vary

The ISO 9000:2000 guidelines define traceability as the “ability to trace the history, application or location of that which is under consideration” (ISO, 2000).¹ The ISO guidelines further specify that traceability may refer to the origin of the materials and parts, the processing history, and the distribution and location of the product after delivery.

This definition of traceability is quite broad. It does not specify a standard measurement for “that which is under consideration” (a grain of wheat or a truckload), a standard location size (field, farm, or county), a list of processes that must be identified (pesticide applications or animal welfare), where the information is recorded (paper or electronic record, box, container or product itself), or a bookkeeping technology (pen and paper or computer). It does not specify that a hamburger be traceable to the cow or that the wheat in a loaf of bread be traceable to the field. It does not specify which type of system is necessary for identity preservation of tofu-quality soybeans, for quality control of cereal grains, or for guaranteeing correct payments to farmers for different grades of apples.

Complete Traceability is Impossible

The definition of traceability is necessarily broad because traceability is a tool for achieving a number of different objectives. No single approach is adequate for every objective. Even a hypothetical system for tracking beef, in which consumers scan their packet of beef at the check-out counter and receive information on the date and location of the animal’s birth, lineage, vaccination records, acreage of pasturage, and use of mammalian protein supplements, is incomplete. It does not provide traceability with respect to pest control in the barn (a potential food safety issue), use of genetically engineered feed, or animal welfare attributes like pasturage hours and playtime. There are hundreds of inputs and processes in the production of beef. A system for tracking each and every input and process with a degree of precision adequate for every objective would be virtually impossible.

The characteristics of good traceability systems vary and cannot be defined without reference to the system’s objectives. Different objectives help drive differences in the *breadth*, *depth*, and *precision* of traceability systems.

Breadth describes the amount of information the traceability system records. There is a lot to know about the food we eat, and a recordkeeping system cataloging all of a food’s attributes would be enormous, unnecessary, and expensive. Take for example, a cup of coffee. The beans could come from any number of countries; be grown with numerous pesticides or just a few; grown on huge corporate organic farms or small family-run conventional farms; harvested by children or by machines; stored in hygienic or pest-infested facilities; decaffeinated using a chemical solvent or hot water. A traceability system for one attribute does not require collecting information on other attributes.

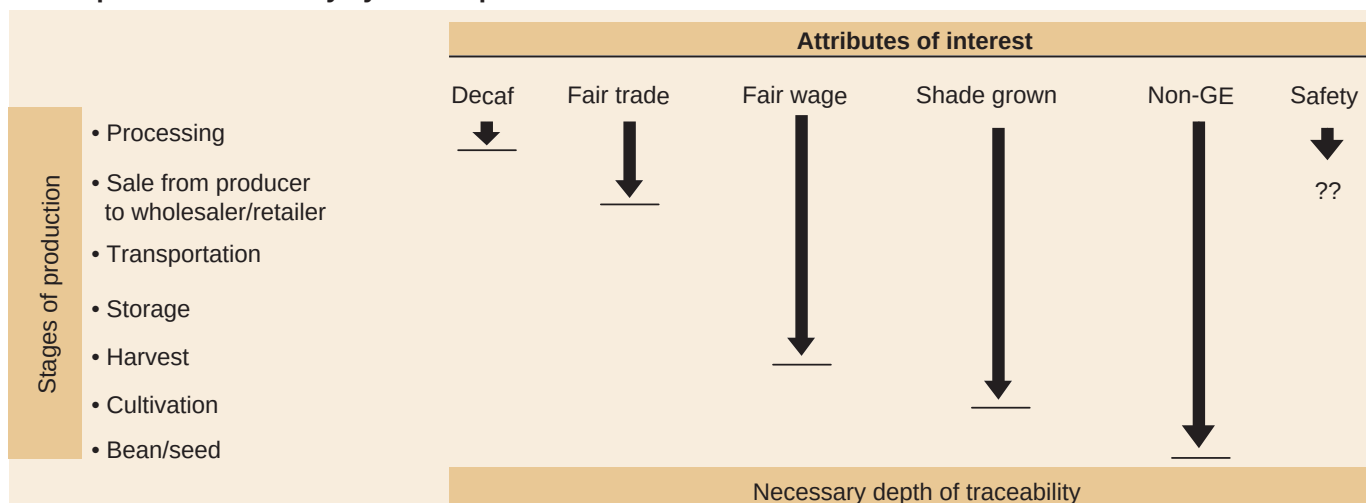
The *depth* of a traceability system is how far back or forward the system tracks. In many cases, the depth of a system is largely determined by its breadth: once the firm or regulator has decided which attributes are worth tracking, the depth of the system is essentially determined. For example, a traceability system for decaffeinated coffee would only need to extend back to the processing stage (figure 1). A traceability system for fair trade coffee would only need to extend to information on price and terms of trade between coffee growers and processors. A traceability system for fair wage would only need to extend to harvest; for shade grown, to cultivation; and for non-genetically engineered (GE), to the bean or seed. In other cases, the depth of the system is determined by quality or safety control points along the supply chain. In these cases, traceability systems may only need to extend back to the last control point, that is the point where quality or safety was established or verified. For example, a firm’s traceability system for pathogen control may only need to extend to the last “kill” step—where product was treated, cooked, or irradiated.

Precision reflects the degree of assurance with which the tracing system can pinpoint a particular food product’s movement or characteristics. Precision is determined by the unit of analysis used in the system and the acceptable error rate. The unit of analysis, whether container, truck, crate, day of production, shift, or any other unit, is the tracking unit for the traceability system. Systems that have large tracking units, such as an entire feedlot or grain silo, will have poor precision in isolating safety or quality problems. Systems with smaller units, such as individual cows, will have greater precision. Likewise, systems with low acceptable error rates, such as low tolerances for GE kernels in a shipment of conventional corn, are more precise than systems with high acceptable

¹ ISO is a worldwide federation of national standards bodies which promotes the development of standardization and international standards for a wide range of products. ISO 9000 guidelines are quality management system standards.

Figure 1

The depth of a traceability system depends on the attributes of interest



error rates. In some cases, the objectives of the system will dictate a precise system while for other objectives a less precise system will suffice.

The breadth, depth, and precision of private traceability systems will vary depending on the objectives of the systems and the corresponding benefits and costs to the firm. Though at first glance this variability may appear to indicate deficiencies in the private supply of traceability, it is actually an indication of efficiency. Firms collect information on an attribute and track its flow through the supply chain only if the net benefits (benefits minus costs) of doing so are positive. Likewise, they invest in precision only if the benefits outweigh the costs. Because firms balance the costs and benefits of traceability, they tend to efficiently allocate resources to building and maintaining these systems.

Firms Consider a Wide Range of Costs and Benefits

Traceability systems that yield positive net benefits to the firm are a worthwhile investment; those yielding negative net benefits are not worthwhile to the firm. Below, we examine the range of benefits and costs that firms consider when determining the efficient breadth, depth, and precision for their traceability systems.

Benefits of Traceability

Firms have three primary objectives in developing, implementing, and maintaining traceability systems: to improve supply management; to facilitate traceback for food safety and quality; and to differentiate and market foods with subtle or undetectable quality attributes. The benefits associated with these objectives range from lower-cost distribution systems, reduced recall expenses,

and expanded sales of products with attributes that are difficult to discern. In every case, the benefits of traceability translate into larger net revenues for the firm. Firms establish traceability systems to achieve one or more traceability objectives—and to reap the benefits. These benefits are driving the widespread development of traceability systems across the food supply chain.

Objective/Benefits I: Traceability for Supply

Management During 2000, American companies spent \$1.6 trillion on supply-related activities, including the movement, storage, and control of products across the supply chain (State of Logistics Report, 2001). The ability to reduce these costs often marks the difference between successful and failed firms. In the food industry, where margins are thin, supply management is an increasingly important area of competition.

An indispensable element of any supply management strategy is the collection of information on each product from production to delivery or point of sale. The idea is “to have an information trail that follows the product’s physical trail” (Simchi-Levi, 2003, pg. 267). Information trails, or in other words, traceability systems, provide the basis for good supply management. A business’s traceability system is key to finding the most efficient ways to produce, assemble, warehouse, and distribute products. The benefits of traceability systems for supply management are greater the higher the value of coordination along the supply chain.

Electronic systems for tracking inventory, purchases, production, and sales have become an integral part of doing business in the United States. A few big retailers such as Wal-Mart and Target have even created proprietary supply-chain information systems that they require their suppliers to adopt. In addition to private systems, U.S. firms

may also use industry-standard coding systems, such as UPC codes (see box, “From UPC to RSS: Tracking Technologies Drive Down the Costs of Precision”). These systems are not confined to packaged products. The food industry has developed a number of complex coding systems to track the flow of raw agricultural inputs to the products on grocery store shelves. These systems are helping to create a supply management system stretching from the farm to the retailer.

Evidence that American companies are embracing new sophisticated tracking systems can also be found in macro-economic statistics. The success of traceability systems in helping to control inventory costs is reflected in national inventory-to-sales ratio statistics. Over short time periods, inventories may rise or fall, but a consistent pattern in which inventories fall relative to a firm’s total sales indicates that the firm is getting better at keeping track of its inputs and outputs and it is taking advantage of that knowledge. Figure 2, showing the ratio of private inventories to final sales of domestic business, displays a declining time trend, falling by half since the end of WWII (U.S. Department of Commerce, 2003).

The same trend can be observed in many sectors of the domestic food industry. Figure 3 shows the ratio of end-of-year inventories to total value of shipments for proxies for the dairy, grain, and sugar industries (Bartlesman, Becker, and Gray, 2000). In every case, the inventory-to-sales ratio fell, with the largest decline in the cereal sector, where the ratio fell from over 8 percent to approximately 3 percent. The downward trend in inventories in major components

of the food industry reflects growing efficiencies in supply management, including traceability systems.

Across the economy, firms are adopting systems to more efficiently manage resources. In many cases, new tracking/information systems are at the heart of these efforts. The depth, breadth, and precision of these systems vary across industries and firms, mirroring the distribution requirements of the enterprise.

Objective/Benefits 2: Traceability for Food Safety and Quality Control Product-tracing systems are essential for food safety and quality control. Traceability systems help firms isolate the source and extent of safety or quality-control problems. The more precise the tracing system, the faster a producer can identify and resolve food safety or quality problems. Firms have an incentive to invest in traceability systems because they help minimize the production and distribution of unsafe or poor quality products, which in turn minimizes the potential for bad publicity, liability, and recalls.

Traceability systems can help track product distribution and target recall activities, thereby limiting the extent of damage and liability. Most, if not all, voluntary recalls listed on USDA’s Food Safety and Inspection Service website refer consumers to coded information on products’ packaging to identify the recalled items. The advent of grocery store or club cards to track sales enhances the potential for targeted recall information. Grocery stores could use their sales data to identify and then warn buyers of recalled products. Some have

Figure 2

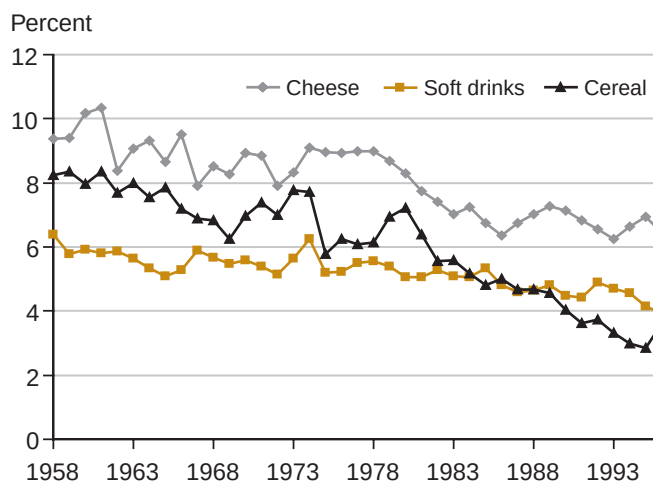
Ratio of private inventories to final sales of domestic business--seasonally adjusted, 1946(4)-2003(1)



Source: Bureau of Economic Analysis, National Income and Product Accounts.

Figure 3

Ratio of inventories to total value of shipments for selected food industries, 1958-1996



Source: Bartlesman, Eric J., Randy A. Becker, and Wayne B. Gray. “NBER-CES Manufacturing Industry Database.” www.nber.org/nberces/nbprod96.htm. Inventories are measured at end of year.

From UPC to RSS: Tracking Technologies Drive Down the Cost of Precision

Ever since a 10-pack of Wrigley's Juicyfruit gum was scanned at the checkout counter in 1974, bar codes have become ubiquitous in the U.S. grocery stores. Almost everything we buy has packaging with printed bar codes. In the food industry, the vast majority of packaged products bear bar codes, as do a growing number of bulk foods, like bagged apples and oranges.

The Uniform Code Council (UCC), a non-profit private company that establishes and promotes multi-industry standards for product identification, created bar codes in response to the needs of food manufacturers and retailers who were interested in speeding the checkout process at the grocery store and for improving inventory management (Uniform Code Council, 2003). Bar codes contain a series of numbers reflecting type of product and manufacturer (the UPC 12-digit code), and a series of numbers assigned by the manufacturer to nonstandard production or distribution details. Each product, including those with different size packaging, contains a unique UPC code. When a package is scanned under a laser beam at the checkout counter, the store's central computer reads the UPC number, records the sale, and marks the change in inventory. Recently, UCC has developed an extension of UPC codes to 14 digits called the Global Trade Item Numbers (GTIN) system, which contains expanded information about companies, products, and product attributes worldwide (Global Trade Item Numbers Implementation Guide, 2003).

The success of the original UPC system has combined with technological advances and e-marketing to spur the development of integrated systems that code, track, and manage wholesale and retail transactions within the United States and in the global community. In some cases, buyers manage these systems to monitor supply flow. In other cases, firms establish systems to link suppliers and buyers. For example, EAN.UCC, which is a subsidiary of the UCC and EAN International, a European commercial standard setting organization, has developed an open integrated system to standardize and automate information systems across a supply chain that includes GTINs, along with an industry standard set of 62 product attributes (EAN.UCC, 2003). With an integrated system, the process of entering information into retailers' systems is automated so when new information is logged into the system by the producer, it's added in real time to all systems across a network. With such systems, anyone along the chain can track inputs, production, and inventory by an array of characteristics.

New technologies are spurring the development of even more precise systems. One example of an upcoming technology is the expansion of bar codes to reduced space symbology (RSS) (Rowe, 2001). Currently, stickers with 4-digit price look-up codes on fresh produce identify the product and assist the retailer in inventory management. With RSS, 14-digit GTIN bar codes could be attached to individual items. An apple, a box, and a pallet could all be linked by the same product and grower-shipper codes, with an additional numeric indicating "item," "box," or "pallet." Similarly a package of ground beef could be linked to a packinghouse. Other bar code application

identifiers and numbers could be used as well, including price, weight, sell date, and lot. Having an electronic lot number on a package of ground beef would facilitate a traceback in case of a quality or safety concern. Moreover, customers who purchase specific foods using frequent shopper cards can be quickly identified even if they have discarded the food package. Thus, tracing forward or backward to facilitate supply chain management or quality and safety control would be more easily and swiftly accomplished.

Bar codes have a few disadvantages (Brain, 2003). In order to keep up with inventories, companies must scan the bar code under a laser beam. A more proactive technology would allow a reader to scan a smart label—a computer chip embedded in each product's package, box, or pallet—whether the item remains on the shelf (in the front part of the shelf or hidden in the back) or is sold. For even more efficiency in retail store management, the store could have a "smart setup." In these stores, a consumer could carry out their shopping and exit the store without going to a checkout counter. Instead, a radio frequency identification (RFID) reader embedded in an exit door could read the smart tags simultaneously for each food package. Even detailed attributes could be read such as a 1-quart container of non-fat organic milk with a sale date of January 14, 2004. Inventories on each product with all its unique attributes even including "must sell by date" could be efficiently traced and managed at manufacturing locations, warehouses, distribution centers and grocery stores.

Furthermore, computers at the grocery store and its suppliers' facilities would know automatically which items had been purchased and needed to be replenished. The computers would also be able to automatically notify the consumer's bank of charges and debit the consumer's account.

While this scenario sounds like it may be far in the future, RFID technology is not new and currently is used to track livestock and container cargo on trucks and ships. With RFID tags, ranchers can determine the location and movements of cattle and more quickly round up any particular heifer or steer. With RFID tags, a distributor can determine precisely the location of a cargo ship or truck and the condition of produce in a controlled-atmosphere container. In July 2003, Wal-Mart issued a mandate to its top suppliers requiring the use of RFID tags on pallets and cases by the end of 2004 (Dunn, 2003). As the cost of RFID technology falls, it is possible that, several years from now, we may see RFID tags on many individual food items.

UCC and EAN International are facilitating the use of RFID technology with the establishment of standardized Electronic Product Codes (EPC) and an EPC network (EPCglobal, 2003). Unlike other electronic networks that are proprietary, these will be open to any firm. Already Wal-Mart is requiring its top suppliers to be EPC-compliant. With the use of electronics and widely accepted standards, the number of attributes that can be traced for each food product is nearly limitless.

already done that. For example, during the recent mad cow beef recall, one supermarket chain used its preferred customer cards to identify and warn shoppers who had bought the suspect meat (Anderson, 2004).

Likewise, credit card information could be used to track purchases of contaminated foods. In fact, the Food and Drug Administration (FDA) has used credit card information in its traceback investigations.

The benefits of precise traceability for food safety and quality control are greater the higher the likelihood and cost of safety or quality failures. Where the likelihood and cost of failure are high, manufacturers have large financial incentives to reduce the size of the standard recall lot and to adopt a more precise traceability system. The likelihood of failure differs among food industries because some foods are more perishable or more susceptible to contamination than others. The costs of safety or quality breaches also vary among firms because the value of products and the value of firms' reputations vary. For high-value products, recall costs per item are higher than for low-value products. For firms with valuable reputations, the costs of recall or safety breaches are higher than for firms with little name-brand equity. The costs of safety or quality failures may also be larger in industries where government or consumer-group oversight is more stringent, meaning that the likelihood of detection in the case of a food safety problem is greater.

The benefits of traceability are also likely to be high if other options for safety control are few. If a firm can eliminate safety problems with a simple kill step or through inexpensive testing, then the marginal benefits of a traceability system for monitoring safety are likely to be small. For example, if a firm could use a chemical dip on incoming produce that completely eliminated the risk of pathogen contamination, there would be little value in a traceability system to identify producers of product with high levels of pathogen contamination. Likewise, if safety or quality problems are unlikely to arise in a specific stretch of the production or supply chain, there is little value in establishing traceability systems for that stretch.

Another benefit of traceability systems is that they may help firms establish the extent of their liability in cases of food safety failure and potentially shift liability to others in the supply chain. If a firm can produce documentation to establish that safety failure did not occur in its plant, then it may be able to protect itself from liability or other negative consequences. Traceability systems in themselves do not determine liability, but because they provide information about the production process, including

safety procedures, they have a role in providing evidence of negligence or improper production practices.

Despite the important safety role they play, traceability systems are, however, only one element of a firm's overall safety/quality control system and are designed to complement and reinforce the other elements of the safety/quality system. In themselves, traceability systems do not produce safer or high-quality products—or determine liability. Traceability systems provide information about whether control points in the production or supply chain are operating correctly or not. The breadth, depth, and precision of traceability systems for safety and quality necessarily reflect the control points in the overall safety/quality system and vary systematically across industries and over time depending on safety and quality technologies and innovations.

Objective/Benefits 3: Traceability To Differentiate and Market Foods with Credence Attributes

The U.S. food industry is a powerhouse producer of homogenous bulk commodities such as wheat, corn, soybeans, and meats. Increasingly, the industry has also begun producing goods and services tailored to the tastes and preferences of various segments of the consumer population. In the competition over micromarkets, producers try to differentiate one product from otherwise similar products in ways that matter to customers.

Food producers differentiate products over a wide variety of quality attributes including taste, texture, nutritional content, cultivation techniques, and origin. Consumers can easily detect some attributes—green ketchup is hard to miss. However, other innovations involve credence attributes, characteristics that consumers cannot discern even after consuming the product (Darby and Karni, 1973). Consumers cannot, for example, taste or otherwise distinguish between oil made from GE corn and oil made from conventional corn.

Credence attributes can be content or process:

Content attributes affect the physical properties of a product, although they can be difficult for consumers to perceive. For example, consumers are unable to determine the amount of isoflavones in a glass of soymilk or the amount of calcium in a glass of enriched orange juice by drinking these beverages.

Process attributes do not affect final product content but refer to characteristics of the production process. Process attributes include country-of-origin, free-range, dolphin-safe, shade-grown, earth-friendly, and fair trade. In general, neither consumers nor special-

ized testing equipment can detect process attributes.

Traceability is an indispensable part of any market for process credence attributes—or content attributes that are difficult or costly to measure. The only way to verify the existence of these attributes is through a bookkeeping record that establishes their creation and preservation. For example, tuna caught with dolphin-safe nets can be distinguished from tuna caught using other methods only through the bookkeeping system that ties the dolphin-safe tuna to the observer on the boat from which the tuna was caught. No test conducted on a can of tuna could detect whether the tuna was caught using dolphin-safe technologies. Without traceability as evidence of value, no viable market could exist for dolphin-safe tuna, fair-trade coffee, non-GE corn oil, or any other process credence attribute.

The benefits of traceability (and third-party verification) for credence attributes are greater the more valuable the attribute is to processors or final consumers. Attributes tend to be more valuable the more marketable they are, the higher the expected premiums, and the larger the potential market. Firms will only find it worthwhile to establish traceability to market attributes with the potential to generate additional revenue—and the larger the potential revenue, the greater the benefits of traceability.

Costs of Traceability

Traceability costs include the costs of recordkeeping and product differentiation. Recordkeeping costs are those incurred in the collection and maintenance of information on product attributes as they move through production and distribution channels. In some cases, the recordkeeping system necessary for traceability is very similar to that already maintained by the firm for accounting or other purposes. For example, in the United States, most firms keep records of their receipts and bills. For these firms, one-up, one-down traceability for a standard set of attributes would require little if any change in the firm's accounting system. In other instances, new traceability objectives may require expensive additions to existing recordkeeping systems.

Product differentiation costs are those incurred in keeping products or sets of product attributes separate from one another for tracking purposes. Product differentiation for tracking is primarily achieved by breaking product flow into lots or any other discrete unit defined over a set of common processes or content attributes (see box, "What's a Lot?"). When traceability requirements accommodate production-based lot sizes such as the

amount of production from one shift or the product from one field, traceability differentiation costs are minimal. Likewise, when new traceability objectives accommodate differentiation systems that are already in place for other traceability objectives, the costs of the new traceability systems will be relatively small.

When traceability differentiation requires firms to adopt different or additional criteria for product differentiation, firms could incur large costs—at least in the short run. Such a situation may arise when firms instigate traceability for new credence attributes. For example, the desire to distinguish GE corn from conventional corn has prompted a number of growers and processors to establish new systems to identify and keep the two types of corn separate.

The longrun cost of separating products with different attributes depends on a number of factors, including underlying production technologies and the level of demand. In some cases, a change or addition to existing production lines is the low-cost solution to meet demand. For example, a packer-shipper may determine that installing scanner equipment on conveyer belts to separate fruit by color or size is the most efficient technology. In other cases, firms may choose to differentiate production by establishing separate product lines within the same plant or by sequencing production and thoroughly cleaning production facilities between differentiated product batches. A packer-shipper could run lines at separate times for conventional and organic produce or build separate lines for each attribute. Firms facing large demand may dedicate a whole plant or distribution channel to the production or distribution of one specific product line. Average costs increase when the separation of product lines creates unused capacity, such as underutilized trucks and storage facilities, or requires stopping, cleaning, and restarting production lines. If demand for the differentiated products is sufficient, however, the firm may realize economies of scope and increased net profits.

The level of precision also affects the type and cost of product differentiation. Systems requiring a high degree of accuracy also tend to require stringent systems for separating crops or products. There are two primary approaches for separating attributes:

- *A segregation system separates one crop or batch of food ingredients from others. Though segregation implies that specific crops and products are kept apart, segregation systems do not typically entail a high level of precision. In the United States, white corn is chan-*

What's A Lot?

Product differentiation for tracking is achieved by breaking product flow into lots, or any other discrete unit defined over a set of common process or content attributes. Lots are the smallest quantity for which firms keep records. Firms may choose among an infinite array of unit sizes, shapes, or time, defining their own lot size by the quantity of product that fits in a container, that a forklift can move on a pallet, or that fills a truck. A lot may be an individual animal or group of animals, or production from an entire day or shift. Firms that choose a large lot size for tracking purposes, such as a feedlot or grain silo, will have more difficulty isolating safety or quality problems than a firm that chooses a smaller size. A smaller lot size, such as an individual cow or container, will allow greater precision.

In choosing lot size, firms typically consider a number of factors, including accounting procedures, production technologies, and transportation. As these factors vary within and among industries, lot size varies from plant to plant. There is no standard traceability unit. Furthermore, a firm is likely to have a different lot size for incoming and outgoing products. Firms add value in their production and marketing practices by commingling, transforming, and processing products. Clearly the incoming products for a meat processor and slaughterhouse (for example, group of pigs) differ from the outgoing product (boxes of primal cuts and consumer-ready products). The size and shape of a lot is therefore likely to change at each processing juncture. Some firms may find it efficient to maintain depth of traceability by linking incoming and outgoing lots, while others may not.

Consider two examples. An apple packer-shipper may use accounting procedures to choose the incoming lot size. The shipper may receive apples from a number of growers and

must pay each grower based on the type, size, and grade of the product. Since these attributes are known only after the apples have been sorted, each grower's apples need to be kept separate in the packing line. These accounting procedures thus influence the lot size of product entering the packing-house. As apples are sorted, packed, and shipped, a packing-house may choose to make a lot the number of boxes that can be loaded onto a truck. One or several growers' apples could be loaded together—it is most cost-effective to fully pack a truck. There may be food safety and quality concerns that motivate a shipper to keep a lot size no larger than a truckload. In the case of a food safety problem—for example, a piece of metal or glass found in an apple—the shipper may want to limit the size of a recall and limit the number of affected growers.

The lot for a farrow-to-finish operation, a farm where pigs are born, raised, and prepared for slaughter, might be a batch or group of pigs. When the batch is moved from one stage of production to another, the all-in, all-out production system allows for cleaning the facilities between batches. This method meets the farmer's objective of preventing disease from spreading from one batch of pigs to another (Hayes and Meyer, 2003). Commingling batches of pigs raises the potential for disease. The slaughterhouse may process several batches of pigs in a shift or day, packing the outgoing product—various cuts of pork—in boxes. Each box may specify the name and address of the packer, the lot number, and place and time of production, allowing the firm to track similar products. This reflects the packer's objective of efficiently managing large volumes of meat and concern for food safety. If the packer or Federal or State authorities discover that there is contaminated pork, they can identify product by lot number and inform retailers and/or consumers.

neled through the bulk commodity infrastructure, but it is segregated from other types of corn.

- An *identity preservation* (IP) system identifies the source and/or nature of the crop or batch of food ingredients. IP systems are stricter than segregation systems and often require containerization or other physical barriers to guarantee that certain traits or qualities are maintained throughout the food supply chain. Tofu-quality soybeans are put into containers to preserve their identity. Produce treated to meet phytosanitary requirements of foreign countries is segregated by box to preserve its identity.

The distinction between “IP” and “segregation” is often blurred and a “strict segregation” system may be more

precise than a loose IP system. Regardless of the exact terminology, precise systems requiring that products be strictly separated will likely be more expensive than others because such systems are usually more expensive to develop and maintain than loose systems.

The level of precision of the traceability system may also influence recordkeeping costs. Recordkeeping expenses tend to rise with smaller lot sizes. Five tons of production broken into 5 one-ton lots require less paperwork than the same quantity broken into 1,000 ten-pound lots. In addition, the bookkeeping records required to maintain a highly accurate traceability system tend to require more detail and expense than those for less exacting systems. For example, a traceability system for stringent pathogen control will require more

sampling, testing, and verification paperwork than a system designed for less stringent control.

Both recordkeeping and differentiation expenses tend to rise with the complexity of the production and distribution systems. Products that undergo a large number of transformations on their way to market generate a lot of new information and are typically more difficult to track than products with little processing. Food products vary considerably with respect to the number of handlers and manufacturers and the degree of commingling and processing. Lettuce picked in the field and sold directly to retailers is relatively easy to track. Tracking a chicken potpie is more challenging. The process of transforming the wheat to wheat flour, the chicken and the vegetables to bite size pieces, and combining all the raw ingredients into a pie generates a trail of numerous different lots that themselves are composed of commingled lots.

Products that are bought and sold numerous times also tend to generate higher bookkeeping and differentiation expenses than those that remain within the same company. Any time product is passed from one firm to another, new paperwork is generated as firms link receipts with product and reconcile or adjust lot numbers and sizes. New coding and software technologies are helping to drive down the costs of linking supply-management records across the food chain and of coordinating the flow of product along the chain. In many sectors of the food supply chain, new information technologies are helping push down the cost of recordkeeping and stimulating investment in traceability systems. As mentioned before, electronic systems for tracking inventory, purchases, production, and sales are becoming an integral part of doing business in the United States.

Vertical integration and contracting are other methods for reducing the costs of tracing and supply management. Vertically integrated firms and firms that contract along the supply chain for specific attributes are often

better able to coordinate production, transportation, processing, and marketing. They are able to respond to consumer preferences for select quality attributes and provide consistency of product. Vertically integrated firms can also adopt the same recordkeeping system across the chain to streamline product coordination. Thus, these food suppliers can attain value and limit the cost of traceability systems.

Benefits and Costs Vary Across Industries and Time

The development of traceability systems throughout the food supply system reflects a dynamic balancing of benefits and costs. Though many firms operate traceability systems for supply management, quality control, and product differentiation, these objectives have played different roles in driving the development of traceability systems in different sectors of the food supply system. In some sectors, food scares have been the primary motivation pushing firms to establish traceability systems; in others, the growth in demand for high-value attributes has pushed firms to differentiate and track attributes; in yet other sectors, supply management has been the key driving force in the creation of traceability systems. Different types and levels of costs, reflecting differences in industry organization, production processes, and distribution and accounting systems affect traceability adoption.

The dynamic interplay of objectives, benefits, and costs has spurred different rates of investment in breadth, depth, and precision of traceability across sectors—and continues to do so. Table 1 summarizes key factors affecting the benefits and costs of traceability systems. These factors vary across industries and across time, reflecting market dynamics, technological advances, and changes in consumer preferences. Changes in the factors influence traceability benefits and costs, thereby influencing the private sector's tracking capabilities.

Table 1—Major factors affecting the costs and benefits of traceability

Factors affecting benefits	Factors affecting costs
■ The higher the value of coordination along the supply chain, the larger the benefits of traceability for supply-side management ■ The larger the market, the larger the benefits of traceability for supply side management, safety and quality control, and credence attribute marketing ■ The higher the value of the food product, the larger the benefits of traceability for safety and quality control ■ The higher the likelihood of safety or quality failures, the larger the benefits of reducing the extent of failure with traceability systems for safety and quality control ■ The higher the penalty for safety or quality failures, where penalties include loss of market, legal expenses, or government-mandated fines, the greater the benefits of reducing the extent of safety or quality failures with traceability ■ The higher the expected premiums, the larger the benefits of traceability for credence attribute marketing	■ The wider the breadth of traceability, the more information to record and the higher the costs of traceability ■ The greater the depth and the number of transactions, the higher the costs of traceability ■ The greater the precision, the smaller and more exacting the tracking units, the higher the costs of traceability ■ The greater the degree of product transformation, the more complex the traceability system, the higher the costs of traceability ■ The larger the number of new segregation or identity preservation activities, the higher the costs of traceability ■ The larger the number of new accounting systems and procedures, the more expensive the start-up costs of traceability ■ The greater the technological difficulties of tracking, the higher the cost of traceability