Implementing a National Animal Identification and Traceability Program: Economic Assessment using a Dynamic Model of U.S. Beef Cattle

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Abstract

This article quantifies the economic impacts of a mandatory national animal identification and traceability system on the U.S. beef cattle producers. Using a dynamic model of the U.S. beef cattle and rich cattle industry data, we estimate the short-run and long-run impacts and how these impacts change over time. In particular, we quantify the producer surplus losses from traceability systems. We show how the prices and quantities would change with the increased costs associated with the traceability system. In the short-run, the aggregate change in producer surplus is negative. Over time, the losses in producer surplus decline and in the long-run the producer surplus would be positive. We also quantify the changes in producer surplus with different cost-sharing programs under different adoption rates.

1 Introduction

Animal identification and traceability has become a global standard. They are essential components of enhancing food safety and managing both animal and human health. Major beef exporting countries around the world have introduced mandatory traceability systems in order to protect domestic livestock health and to increase access to international markets. Similarly, beef importing countries are also implementing traceability systems for their domestic production and demanding the same or better from their international partners. Murphy et al. (2008) note that animal identification (ID) systems "are becoming prerequisites to international trade" (page 284).

Several countries have developed different types of traceability systems that meets to international standards and are flexible for their domestic production. These systems are not similar and differ in many ways. They differ in the technologies used, the characteristics of the system, and in the breadth, depth, and precision (Golan et al., 2004). Despite the differences in traceability systems between nations and between species within the same nation, a food product that can be traced from its origin to the shelves of a retail store has become an international requirement to protect animal and human health and provide assurance to consumers around the world (Schroeder and Tonsor, 2012).

Most beef exporting countries adopt to traceability systems in response to the importing country's requirements, in order to remain competitive, maintain and enhance their market share (Souza-Monteiro and Caswell, 2004). In major beef producing and trading countries there are four patterns of adoption to traceability systems are observed. These include voluntary systems, industry managed mandatory programs for animal ID, enforcing a mandatory traceability to increase export shares, and adoption of mandatory traceability in response to consumer concerns (Souza-Monteiro and Caswell, 2004).

Having a sophisticated mandatory animal ID and traceability system would put that country in a huge advantage in beef exports and in responding to any animal health emergencies, compared to the countries that do not have such a system. Of the world's largest beef exporting countries, six countries have some form of mandatory traceability system. Only the U.S. and India have not employed a mandatory animal ID and traceability systems. Smith et al. (2005) note that the U.S. is "lagging behind many countries in developing traceability systems for food in general and especially for livestock, and their products" (page 174). This is because, the U.S. cow-calf sector comprise numerous small, decentralized operations where the benefits of the traceability system are not directly observed (Schulz and Tonsor, 2010a,b; Tonsor and Schroeder, 2006). Unlike the major beef export and import countries, the U.S. federal government encourages a voluntary animal tracing system rather than a mandatory system. If the trends continue on the same path, the U.S. could become less competitive and potentially lose access to global markets (Pendell et al., 2013; Schroeder and Tonsor, 2012; Murphy et al., 2009).

A workable animal identification and traceability system means the ability to, promptly trace back, isolate and alleviate a disease outbreak and reduce disastrous economic impacts, due to restricted access to markets resulting from it. With animal identification and traceability systems in place, one can notably decrease the spread, span, and economic repercussions of any highly contagious animal disease (Saatkamp et al., 1997, 1995). Studies by Zhao et al. (2006) and Disney et al. (2001) suggest that in an event of foot-and-mouth disease (FMD) outbreak, having a cattle identification system can provide economic benefits and decrease adverse economic losses that result from the outbreak. In a simulated FMD outbreak in southwest Kansas, Pendell (2006) found that the outbreak could be reduced within 12 days with a high-level cattle identification system in place. Further, the analysis found that the cost associated with disease outbreak control fell by 65% percent between a low adoption and high adoption scenario. In another study, Pendell et al. (2007) estimated economic impacts of a simulated outbreak of FMD in Kansas. The estimated losses are $35 million with the introduction of disease in a single cow herd in southwest Kansas, the losses magnify to $1 billion if the same disease were introduced at 5 large feedlots simultaneously. These losses could be mitigated with a standardized traceability system.

A crucial part of designing an animal identification and traceability system is determining the benefits and costs to participating producers and how participation might adjust to design changes. Determining the costs and benefits is difficult within the U.S. beef cattle industry due, in part, to the highly segmented nature of production. Traceability starts at the cow-calf level, which is possibly the most heterogeneous segment in the industry. Live animal production stages also include seedstock, backgrounding/stocker, and feedlot. From birth to slaughter, cattle could change ownership several times and travel long distances. This adds to the difficulty of cattle traceability. The costs associated with traceability are expected to vary across sectors of the supply chain and within each sector. Pendell et al. (2011) found that the costs also vary depending on the size of operation and whether cow-calf operations were currently tagging cattle. Low levels of adoption can be achieved with less cost while higher marginal cost would be required to achieve higher adoption levels (Pendell et al., 2011).

The producers' benefits from traceability are often interconnected, multi-faceted, and not as straightforward. For producers, traceability systems can protect animal health, expand their business options, maintain flexibility in marketing, and limit quality and safety failures (World Perspectives Inc, 2018). Other benefits for producers include avoidance of bans on sales, loss of reputation, and the mandatory destruction of assets (Souza-Monteiro and Caswell, 2004). Mitchell et al. (2020) argues that voluntary traceability is a product characteristic and that there is an implicit market for food products with that characteristic. Traceability can be leveraged to differentiate a product from others inducing higher market price. In regard to societal benefits, traceability offers public health benefits by reducing the food-borne illness, and faster identification of new diseases that are threat to both human and animal health.

With the increasing popularity and awareness of food safety in recent decades, the domestic and international consumers value the characteristics of food that can be verified through traceability. Willingness to pay (WTP) and demand for food that can be traced back to the source is also increasing. Through binding experiments, Dickinson and Bailey (2002) illustrated that consumers were WTP an average of additional \$0.50 for a traceable roast beef sandwich. Loureiro and Umberger (2007) noted that consumers, on average, are WTP a premium of \$1.899 per pound of traceable steak. Pouliot and Sumner (2008) claim that consumers WTP for traceable food product increases from food safety perspective. Although quantifying the increased demand for meat caused by the adoption of traceability program is challenging, Dickinson and Bailey (2002) noted that WTP premiums for meat traceability exceeds 7 percent. All of this indicates that economic incentives play an important role in adopting to the traceability systems. When systematically employed and executed, traceability systems can have noticeable economic and societal benefits.

The objective of this study is to estimate the economic impacts of a mandatory animal identification and traceability system on the U.S. beef cattle producers. In this paper we use a dynamic model of U.S. beef cattle to estimate the producer surplus changes associated with adopting to animal ID and traceability system. The dynamic model incorporates costs of traceability systems, rich data set, uses numerical methods, and differentiates the types of cattle. The model is used to quantify the short-run and long-run economic impacts and how these impacts vary over time on the producers, with various degrees of adoption to the traceability system. With various controversies surrounding a nationally standardized traceability system in the U.S., it is imperative to accurately estimate and understand the economic impacts of the system. With U.S. beef considered high quality and safe in the domestic and international markets, our study would be of interest to policymakers and industry stakeholders.

2 Animal Identification in the United States

Animal ID in the U.S. has been present in many forms, primarily to verify animal ownership, breeding herds, and manage animal disease (Schroeder and Tonsor, 2012). The livestock industry has been using some form of identification to maintain individual animal records. In the U.S., animal identification programs were used to eradicate brucellosis from the national cowherd. As the disease neared eradication, the program was scaled down and the importance of the program vanished (Murphy et al., 2009). However, concerns about the general animal health and rapid tracing in the event of a disease outbreak motivated the government officials and industry stakeholders to develop a standardized identification system. A single incident of bovine spongiform encephalopathy (BSE) in 2003 raised the interests in a national animal identification system.[1] Since then, the U.S. has developed an animal identification system known as the National Animal Identification System (NAIS) to better trace and identify animals. The NAIS was originally designed as a mandatory system (Murphy et al., 2008). Upon receiving a significant backlash, the United States Department of Agriculture (USDA) altered the guidelines and released an updated plan in November 2006 stating that NAIS would become a voluntary program (USDA-APHIS, 2007). As of 2006, NAIS was a voluntary federal program administered by the USDA's Animal and Plant Health Inspection Service (APHIS) that allowed the producers who were not a part of the program to participate at their will (USDA-APHIS, 2007).

The NAIS was designed to improve and enhance animal tracing to protect the U.S. livestock and poultry health. The primary objectives of the NAIS were to respond quickly to any animal health emergencies with potentially catastrophic economic, animal and human health consequences, and to protect the domestic and export markets for U.S. beef, ultimately increasing the consumer demand which benefits the producers (Pendell et al., 2010). The program showed success in the poultry and pork industries and has even received general support. However, some portions of the U.S. cattle industry strongly opposed the program and had concerns about the program. Concerns

[1] 53 countries banned the U.S. beef immediately after the incident (Pendell et al., 2010).

included costly implementation, reliability of electronic identification devices, and confidentiality of data (Schroeder and Tonsor, 2012; Greene, 2010; Schulz and Tonsor, 2010a; Blasi et al., 2009; Bailey and Slade, 2004).

The concerns of the producers listed above were reflected in the beef industry participation in the program. Greene (2010) reports the participation for major species in the initial phase of NAIS. The participation of poultry, swine, and cattle industries were 95%, 80%, and 18% respectively. With low participation by the cattle industry and strong resistance to voluntary NAIS, in 2010, USDA abandoned the existing NAIS and introduced a new approach called Animal Disease Traceability (ADT) (USDA-APHIS, 2010). This new approach allowed the states and tribal nations to design and implement with-in state animal ID and traceability system. This with-in state program is administered by the state ensuring low federal government involvement and greater flexibility. The flexibility with ADT enabled the individual state to respond to the needs and interests of its producers. In the new revised program, however, the USDA required that all the animals moving between states must have an ID that can be used to trace the animals' origin of state or tribal nation. According to the APHIS Animal Disease Traceability Assessment Report (USDA-APHIS, 2017), the key principles of ADT are : i) official identification when cattle move through the states, ii) administration by the states and tribal nations increasing flexibility, iii) encouraging the use of low-cost technologies, and iv) improving transparency. Although the current ADT framework showed success in general, according to APHIS ADT program review report (USDA-APHIS, 2018), the industry stakeholders are concerned about state differences/lack of standardized system, too flexible and too many exemptions creating confusion, and inconsistencies in regulation. All of this indicates that a standardized national traceability system that is consistent across states and that is flexible to adopt can address the major concerns.

There are currently no mandatory beef cattle traceability programs in the U.S. However, private, voluntary traceability systems are widely used in the industry (Golan et al., 2003). Additionally, voluntary traceability systems such as the USDA's Quality Systems Assessment Program, Process

Verified Program, and Non-Hormone Treated Cattle Program are popular, as the demand for more details on source, production, and processing of food products is increasing and the firms strive to satisfy the consumer needs (Smith et al., 2005; Souza-Monteiro and Caswell, 2004).

Whether the program should be mandatory or voluntary, government regulated or not, is the big question to be answered. A firm would adopt to voluntary traceability systems if adopting would increase net revenues, otherwise they would not be adopted (Golan et al., 2004). Golan et al. (2004) argue that private-borne costs in general are not equal to the social benefits of traceability adoption, which means that there are no incentives for the private firms to bear the costs. Golan et al. (2004) also suggest that government programs are often ill-fitted and programs aimed at increasing incentives for the private firms could be the best way to build the traceability systems. Resende-Filho and Hurley (2012) note that government regulated mandatory traceability would increase costs for food processors and potentially not result in safer food. Industry should take this important information into account when developing or expanding traceability system in the U.S. Mitchell et al. (2020) recommend that a joint partnership between the U.S. government and industry could be a way to increase participation in traceability programs. Pendell et al. (2011) recommend that the U.S. should candidly analyse current traceability systems in order to be competitive in the international markets. Some philosophical changes maybe also be required in order for the U.S. to position itself with rapidly changing world standards.

3 Literature Review

The economics of food and livestock traceability, in general, is studied extensively. The research studies can be categorized into preferences for traceability, markets for traceability, different costs and value of traceability, and aggregate impacts of livestock traceability.

Preferences and perceptions for traceability have been widely studied in the literature. Some studies measured consumer's WTP for traceability, while others studied the producer preferences for traceability. Dickinson and Bailey (2002) and Hobbs et al. (2005) used experimental auctions to compute the consumer WTP and preferences for traceable beef and pork sandwich. These studies show that consumers are WTP a premium when additional information is included to ensure food safety and farm production methods along with product traceability. Although traceability is important, additional guarantees that could be verified by the traceability system command a higher premium for the meat products. Schulz and Tonsor (2010a) and Schulz and Tonsor (2010b) examine the perceptions and preferences of cow-calf producers for voluntary traceability systems. Using survey data, Schulz and Tonsor (2010a) determines that the producer's characteristics play an important role in their decision to participate. Producer experience, membership in cattle associations influence participation in traceability systems. In addition, the high costs, the confidentiality of the information, the liability, and the reliability of the systems are main concerns and hinder the producer participation in the voluntary traceability systems. Schulz and Tonsor (2010b) notes that the preferences of the cow-calf producers for the traceability system are heterogeneous. The willingness to change estimates from the study suggest that a premium is needed by the producers to be indifferent between participating and not participating, government or private managed traceability systems. These premiums vary by the producers as well. Furthermore, producers whose premises are not registered are found to show strong resistance to the traceability program.

Using the data of the price of steers in Quebec and Ontario and by employing a hedonic framework, Pouliot (2011) measured the packer WTP for the traceability of steers. The study estimated that a premium between 0.02 and 0.05 Canadian dollars per pound of carcass is paid for the traceability of steers. The study further claims that the packers may be WTP a premium for traceability because it acts as a product attribute. By recognizing participation in voluntary traceability can be viewed as a product characteristic and can be used to differentiate the product from products without that characteristic, Mitchell et al. (2020) examines the implicit market for the traceability system. Using survey data and by employing discrete choice models, the study finds that the probability of adopting to electronic traceability is positive for premiums and discounts. Further, the study finds that cost-sharing mechanisms can encourage and increase the participation in traceability programs.

The incentives from traceability may come in several forms, such as saving unexpected costs or improving transparency. Resende-Filho and Buhr (2007) studied the costs of food recalls due to contamination/disease in the absence and presence of traceability. Using simulation strategy, the study finds that in an event of E.coli in ground beef, the costs with food recalls without traceability are higher than the costs with traceability. In another study, Resende-Filho and Hurley (2012) investigates how voluntary traceability can improve food safety. Using a principal agent model, the study qualitatively determines that, the "traceability system alone is neither a necessary nor sufficient condition for inducing further food safety effort when there is some traceability even without the explicit adoption of a traceability system" (page 602). However, with complete anonymity of the food supply, traceability can improve food safety. Similarly, Pouliot and Sumner (2008) argues that increased traceability removes the anonymity of all the parties involved in the supply chain and encourages the farms and food marketing firms to produce and deliver safer food by increasing liability costs. Using the transaction costs approach, Banterle and Stranieri (2008) finds that introduction of traceability systems can increase asset specificity, reduce uncertainty, and increase vertical coordination between firms that previously used oral agreements.

All the above studies provide a thorough understanding of the various factors involved in the traceability systems and are also helpful in understanding the implications of livestock traceability. Much research has focused on the managerial benefits of the traceability, with recent research identifying the benefits of marketing and considering how prices coordinate the supply of cattle traceability. However, knowing the aggregate economic impacts is important to understand whether the livestock traceability system is generally beneficial. In particular, it is important for the policymakers to understand the welfare of the producer (short-run and long-run) when making a decision about implementing and mandating the traceability system.

Pendell et al. (2010) examined the economic impacts of adopting a U.S. national animal identification system (NAIS) on domestic livestock, meat producers and consumers. The study used the equilibrium displacement model (EDM) to employ a multi-market simulation model. The simulation model is used to estimate how the costs with different adoption rates (30%, 50%, 70%, 90% adoption rates) of livestock traceability would impact the U.S. producers and consumers. The study also considered the supply changes with the adoption of livestock traceability. By including the supply changes along with the costs, the study computed the aggregate impacts. Assuming only costs from 90% adoption rate and excluding benefits, the short-run and long-run aggregate producer surplus declines to \$$1,354.51$ million and \$23.66 million respectively. Taking into account the increase in WTP for traceable meat, the study computed the change in domestic and international demand that would be required to offset the additional costs of NAIS. The study further conclude that, under 90% adoption rate, a 0.96% (34.1%) increase in domestic (international) demand alone is required such that the producers would not lose any surplus.

In a similar study, Pendell et al. (2013) estimated the economic impacts on the U.S. animal and meat producers and consumers due to the increasing demands (participation in animal age and source verification) for traceability by U.S. beef importers. This study employed EDM to estimate the economic impacts by including costs with 20% and full participation in animal age and source verification (ASV) program. In particular, the study focused on assessing the economic impacts from no expansion in ASV and loss of all beef exports to South Korea and to all North-America separately. In short-run the aggregate producer surplus is found to be positive. In the long-run, however, the aggregate producer surplus decline with the loss of beef exports. The study finds that, with an adoption rate of 20%, a one-time permanent increase in beef exports of 1.01% is required to offset the producer surplus losses. Also, a 29.50% increase in export demand is necessary so that all sectors of beef production do not lose any producer surplus with full adoption of ASV.

Our study also estimates the economic impacts of the traceability system. This study is different from other studies. We use a dynamic model developed for the U.S. beef cattle to estimate the economic impacts. Our work complements the existing literature on the traceability impacts on the producer. In contrast to the standard literature on estimating impacts of traceability systems, we take a different approach by isolating the beef industry and using a dynamic model to estimate the impacts. In addition, our study bridges the gap in the literature by examining different types of cattle, especially fed cattle and cull cows.

The studies that analysed the impacts of introduction of traceability systems on the U.S. producers are based on static EDMs. These models are useful for policy recommendations and can provide reasonably accurate predictions in the short-run. However, dynamics are essential characteristics in cattle production and markets. Incorporating dynamics will provide more accurate estimates of the economic impacts of policies affecting the cattle sector and how these impacts will vary over time. A dynamic model that calibrates directly from data, rather than relying on the static counterfactuals and parameter estimates from literature, can help understand the impact of a policy over time and help the policymakers design effective policies. In this study, we use our dynamic model to accurately estimate the aggregate impacts of a mandatory national animal identification and traceability system on the cattle producers and investigate how the impacts change over time.

4 Costs Associated with Traceability Systems

Our study relies on the previous research to incorporate additional costs in the model. The Blasi et al. (2009) and Pendell et al. (2011) reports provide estimated costs for implementing traceability systems in the beef industry. Although they are two different studies, the approach in both studies to compute the costs is similar. As noted in the introduction, the costs associated with the traceability system vary across the sectors in the industry. The economies of size are present in the industry, which indicates that cost is also dependent on the size of the operation (higher costs for smaller operations and lower costs for large operations). In addition, the costs also depend on whether the operation is currently tagging their animals or not. An operation that is already tagging the animals can adopt to the system more cheaply and quickly than the operations that never tagged their animals.

Blasi et al. (2009) estimated the costs of NAIS in the U.S. The study reports costs for two types of traceability systems: (a) bookend system - which means “the animal is identified individually or in group fashion at its birth location and is terminated at the packing plant” (page 6) and (b) a full tracing system - which “refers to the bookend, tracing, and recording movements of animals (individually or by the group depending on species) through their lifetime as they change ownership”(page 6). Within each sector (cow-calf, backgrounding, feedlots, packing plants), the costs are computed based on the size of operation. Along with the size of operation, the costs in the cow/calf sector are further calculated by the current status of tagging (tagging or not tagging) in the operation. The report found that the highest costs are borne by the cow-calf sector and the costs tend to decrease as the cattle moves through the supply chain.

Pendell et al. (2011) estimated the costs associated with possible increases in traceability adoption for domestic production due to changes in the U.S. meat access in world markets. The study focuses on a specific traceability program called age and source verification (ASV) program to compute the costs. The costs of participating in ASV program which is administered by a private firm are included. The average annual costs per head and per operation are given in the study. These costs are decomposed into just tags and tagging costs and ASV participation costs. Similar to the above study, the costs of traceability varies by sector. Within each sector, they vary by the size of operation and whether the operation is currently tagging or not tagging their animals. The annual cost of the cow-calf sector ranges from \$4.21 (\$5.54) per head for small operations to \$2.40 (\$5.04) per head for large operations that currently tag (currently not tagging) their animals. For backgrounding and feedlot sectors, the annual cost is between \$0.75 and \$0.14, and between \$0.50 and \$0.12 per head respectively. The costs further decline in the packing plant sector, ranging from \$0.47 per head for the smallest facility to \$0.16 per head for the largest facilities.

In this study, we rely on the recent cost estimates of Pendell et al. (2011). Within each sector, we take the weighted average of the tag and tagging costs by operation size and aggregate all the costs to get a final per head cost estimate of implementing traceability. The following tables 1 - 4 lists the costs that we used to get the aggregate cost estimate, which is then used in the analysis.

Table 1: Tag and Tagging Costs for Cow-Calf Sector that currently Tag cattle

Size of Operation by number of head						
1 – 49	50 – 99	100 – 499	500 – 999	1000 – 1999	2000 – 4999	5,000+
\$4.21	\$2.90	\$2.73	\$2.43	\$2.42	\$2.43	\$2.40

Table 2: Tag and Tagging Costs for Cow-Calf Sector that currently not tag cattle

Size of Operation by number of head						
1 – 49	50 – 99	100 – 499	500 – 999	1000 – 1999	2000 – 4999	5,000+
\$5.54	\$5.29	\$5.20	\$5.04	\$5.04	\$5.04	\$5.04

Table 3: Tag and Tagging Costs for Backgrounding Sector

Size of Operation by number of head						
31	104	345	496	722	1453	2963
\$0.75	\$0.43	\$0.22	\$0.19	\$0.20	\$0.16	\$0.14

Table 4: Tag and Tagging Costs for Feedlot Sector

Size of Operation by number of head						
1 – 999	1000 – 1999	2000 – 3999	4000 – 7999	8000 – 15999	16000 – 31999	32000+
\$0.50	\$0.16	\$0.14	\$0.12	\$0.12	\$0.12	\$0.12

5 Data

The model depends exclusively on the data which are measured consistently over time and are publicly available. We use livestock industry data that are compiled and distributed by various U.S. Department of Agriculture agencies. Our data includes total cattle inventory, inventory of replacement heifers, prices received by producers for fed cattle and cows, numbers of animals slaughtered and dressed weight of slaughtered animals.

The National Agricultural Statistics Service (NASS) of the USDA (USDA-NASS, 2020b) compiles cattle inventory data every year and provides a measure in January and July. For our analysis we used the January measure of annual total cattle inventory and replacement heifers. With these measures, we construct the cattle of all age groups in any year.[2] Knowing the age groups in a given year is important as we use these numbers to determine the annual supply of domestic fed cattle and cull cows. Table 5 provides the constructed age distribution of cattle in the U.S.[3]

Table 5: Age distribution of cattle in the U.S. (in number of head)

Year	K	k_3	k_4	k_5	k_6	k_7	k_8	k_9
2006	32702500	5638100	5232885	5075209	4776608	4551624	4258116	3169958
2007	32644200	5863500	5356195	4971241	4821448	4537777	4324043	2769996
2008	32434500	5835400	5570325	5088385	4722679	4580376	4310888	2326447
2009	31793800	5646600	5543630	5291809	4833966	4486545	4351357	1639893
2010	31439900	5550200	5364270	5266448	5027218	4592268	4262218	1377278
2011	30912600	5443000	5272690	5096056	5003126	4775857	4362654	959216
2012	30281900	5134600	5170850	5009056	4841254	4752970	4537065	836107
2013	29631300	5280600	4877870	4912308	4758603	4599191	4515321	687408
2014	28956400	5429200	5016570	4633976	4666692	4520673	4369231	320057
2015	29332100	5556300	5157740	4765742	4402278	4433358	4294639	722044
2016	30163800	6086400	5278485	4899853	4527454	4182164	4211690	977754
2017	31170700	6335200	5782080	5014561	4654860	4301082	3973056	1109862
2018	31466200	6363200	6018440	5492976	4763833	4422117	4086028	319606

Here K represents the total inventory, k_3 represents the replacement heifers, and k_4 to k_9 represents the cows of ages from 4 to 9 years.

[2] The survival rate of cattle in our model makes it easy to compile the age distribution.
[3] For the sake of brevity, we provide data from the last few years.

The constructed domestic supply of fed cattle and cull cows is converted from the number of heads to pounds of meat. We use dressed weights of the slaughtered animals to calculate the meat supply in pounds. Using the monthly dressed weights provided by USDA NASS (USDA-NASS, 2020c), we computed the annual average dressed weights of fed cattle (including steers & heifers) and cull cows.[4] The annual average dressed weights are used to determine the domestic supply of fed cattle and cull cow meat in pounds. With changes in the weight of the cattle over time, it is important to use dressed weights.[5]

In addition to the domestic quantities, we also consider the imports and exports of animals in our analysis. USDA's Foreign Agricultural Service (FAS) Production, Supply and Distribution (PSD) (USDA-PSD, 2020) compiles the annual cattle numbers that include production, imports, exports, and more. We utilize the import and export animal numbers for accuracy purposes. In the tables 6 and 7 the annual supply of the fed cattle and cull cows are listed in number of heads and in pounds of meat, which are constructed based on age distribution and imports and exports. The table 8 contains the dressing weights with which the supply is converted from the number of heads to the pounds of meat.

Table 6: Annual Supply of Fed Cattle

Year	Number of head	Meat in billion pounds
2006	28069668	22.029
2007	28315025	22.608
2008	28195274	22.807
2009	27855265	22.653
2010	27589986	21.854
2011	27275103	22.463
2012	26796622	22.726
2013	25816243	21.552
2014	25436061	21.743
2015	23912308	20.189
2016	23755937	20.230
2017	24509686	22.047

[4]USDA NASS compiles these data from the reports of Food Safety and Inspection Service (FSIS) and the USDA along with data from state-administered non-federally inspected (NFI) slaughter plants.

[5]Using a constant weight could deviate the model from the trends we observe in the real world.

Table 7: Annual Supply of Cull Cows

Year	Number of head	Meat in billion pounds
2006	4885660	2.870
2007	4994480	2.964
2008	5226461	3.073
2009	4838299	2.833
2010	4909893	2.828
2011	4724556	2.761
2012	4923412	2.957
2013	5112632	3.064
2014	4193278	2.577
2015	4260597	2.598
2016	4288690	2.635
2017	4978366	3.277

Table 8: Annual Average Dressed Weight (in pounds)

Year	Fed Cattle	Cows
2006	832.583	623.083
2007	830.083	617.000
2008	838.417	609.500
2009	847.083	609.917
2010	835.167	607.250
2011	840.833	596.583
2012	858.750	608.083
2013	863.500	619.833
2014	872.500	627.333
2015	892.000	644.250
2016	891.000	642.750
2017	878.000	642.583

Our analysis also includes the prices received by the producers for fed cattle (steers & heifers) and cows. Prices play a key role in the analysis. From the monthly prices of USDA NASS (USDA-NASS, 2020a) we compute the annual average price for cows, steers and heifers. The table 9 lists the calculated annual average prices. These prices are further converted into $/pound in the analysis.

Table 9: Annual Average Price (in $/CWT)

Year	Fed Cattle	Cows
2006	92.042	46.742
2007	95.383	48.117
2008	94.467	50.800
2009	85.333	44.850
2010	97.233	54.933
2011	117.167	71.575
2012	123.083	81.975
2013	126.333	82.292
2014	154.333	108.225
2015	149.333	104.108
2016	121.667	74.892
2017	121.917	69.558

6 Model

The dynamic model includes the decision-making process of the producer at each age of the animal (from age 2 to 10). The decision of the producer decision depends on fed cattle price, cull cow price, holding costs, and the stock. Producers make these decisions by making expectations about the prices. The demand for fed cattle and cull cow cattle is derived from the demand for meat. More details on the model can be found at Poddaturi et al. (2020). In contrast to most of the literature, we used observed data, fewer assumptions, constructed age distribution, and numerical methods to calibrate the model and adequately capture the dynamics of the U.S. beef industry.[6]

The model is always forward-looking, we use current data to project the future prices and quantities. In summary, we use observed data for year t to project prices and quantities for the year $t+1$, observed data for year $t+1$ to project the prices and quantities for the year $t+2$ and so on. This process can be carried out either by using the stock of breeding cows (aged three to nine) or total stock of animals and replacement heifers. In our calibration, we use the latter as this will give more accurate estimates since the demand for fed cattle meat and the measurement of total stock

[6]It should also be noted that our model does not depend on the counterfactuals or any other simulated data. Every data element is either observed in the real world or comes from the model.

and replacement heifers are consistent.

6.1 Algorithm used for the analysis:

We employ the following algorithm in *R* programming language to calibrate the model.

- For each year, we get the data of prices, costs, cattle numbers, imports, exports, and the overall demand for meat.
- Use the prices to compute the share metric which is later used to determine the fed cattle meat and cull cow meat.
- Use the cattle numbers to determine the total meat supply.
- The total meat supply and share metric are used to compute the meat supply from fed cattle and cull cows.
- Use the adjustment parameter to adjust for the fed cattle meat and cull cow meat.
- The prices, fed cattle meat, and cull cow meat are then used to estimate the model parameters.[7]
- Use *BBoptim* in *R* to solve for the prices.[8]
- Quantities are computed using the prices obtained in the previous step.
- Repeat the above steps for all available observed data.

The table 10 presents the estimated parameters of the model for each year. Instead of setting the parameters to a single value, we keep them dynamic so that they can move around flexibly with the changes we observe in the data.

The tables 11 and 12 show the estimated fed cattle price, cull cow price, and holding costs and supply of meat respectively. From these tables, it is clear that the model adequately captures the prices and quantities. As mentioned at the beginning of this section, the model uses data from the previous year to estimate the prices and quantities. Noting that, the model captures the prices and

[7] We provide initial values for the model parameters because the expression is not linear. We use *Sum Squared Error* as a loss function to estimate the parameters.

[8] We use the parameters computed in the previous step and give initial values for the prices, since the system of equations is non-linear.

Table 10: Estimated Parameters

Year	$\tilde{\mu}$	$\tilde{s}$
2006	2.004	0.662
2007	2.081	0.702
2008	2.062	0.693
2009	2.034	0.677
2010	1.999	0.660
2011	2.007	0.664
2012	2.090	0.707
2013	1.998	0.659
2014	2.044	0.682
2015	2.106	0.715
2016	2.079	0.701

quantities of the beef industry in general.

Table 11: Observed & Estimated Prices and Costs (in \$/CWT)

Year	p_s	$\hat{p}_s$	p_c	$\hat{p}_c$	h_c	$\hat{h}_c$
2006	92.042	98.403	46.742	48.166	30.321	29.649
2007	95.383	95.075	48.117	44.289	31.424	28.538
2008	94.467	98.098	50.800	46.041	31.099	29.463
2009	85.333	97.614	44.850	48.196	28.100	29.432
2010	97.233	89.381	54.933	41.223	31.990	26.810
2011	117.167	99.075	71.575	53.707	38.509	30.102
2012	123.083	118.446	81.975	71.011	40.404	36.315
2013	126.333	125.840	82.292	79.745	41.485	38.788
2014	154.333	128.149	108.225	81.124	50.623	39.496
2015	149.333	158.378	104.108	104.700	48.988	49.026
2016	121.667	152.770	74.892	101.221	39.984	47.301

$\hat{p}_s$, $\hat{p}_c$, and $\hat{h}_c$ denote the estimated fed cattle price, cull cow price, and holding costs respectively. p_s, p_c, and h_c denote the observed counterparts.

Table 12: Observed & Estimated quantities (in billion pounds)

Year	sl	$\hat{sl}$	cl	$\hat{cl}$
2006	22.029	21.257	2.870	2.823
2007	22.608	22.524	2.964	3.236
2008	22.807	22.782	3.073	3.431
2009	22.653	22.609	2.833	3.123
2010	21.854	21.965	2.828	2.811
2011	22.463	22.540	2.761	3.013
2012	22.726	22.103	2.957	3.198
2013	21.552	21.616	3.064	2.808
2014	21.743	21.199	2.577	2.955
2015	20.189	20.027	2.598	2.933
2016	20.230	20.485	2.635	2.938

$\hat{sl}$ and $\hat{cl}$ denote the estimated fed cattle and cull cow meat respectively. sl and cl denote the observed counterparts.

7 Impacts of Mandatory Animal Identification and Traceability System

We introduce the tag and tagging costs in the model in order to estimate the impacts of a mandatory animal ID and traceability system on the prices and quantities. As stated in section 4, the costs across all the sectors in the beef industry are aggregated to a point estimate and used in the analysis. The estimated cost used in the analysis averages \$7.942 per head per year. Since we are using the cost estimates from Pendell et al. (2011), it is appropriate to introduce the additional costs in the year 2009 in our analysis.[9]

Our algorithm stays the same as in the previous section, but with additional costs. We convert the additional unit cost from dollars per head to dollars per pound of meat for fed cattle and cull cows separately. The model is simulated with the observed data and with additional costs to determine the changes in the price and quantities. The simulation is carried out on the assumption that only costs (without benefits) incurred due to the implementation of mandatory animal ID and traceability

[9]Cost estimates in the study are reported for 2009. So, we introduced the costs in 2009.

system. In this study, we pay close attention to the added costs and consequences of those costs. In order to obtain a quantitative measure, the simulated model changes are compared with the model estimates in section 6. We provide several figures that include the observed, model estimates, and the simulated model estimates with added costs, tables showing the percentage change in price and quantity, as well as change in producer surplus with complete adoption to the traceability program. In addition to the immediate impact (one year after the program) of animal ID and traceability system, we also provide how the impacts change over time.

To understand how the impacts differ for different adoption rates, the model is simulated with different adoption rates. In particular, a 30%, 50%, 70%, 90%, and 100% adoption rates are selected for the simulation. An adoption rate of 90% – 100% can be viewed as a mandatory policy where all the producers adopt to the traceability system. An adoption rate of 30% can be viewed as current participation in the system (Pendell et al., 2010). The remaining adoption rates are selected for the sensitivity analysis.

The costs of the traceability program for fed cattle in 2010 with full adoption are approximately \$0.415 billion. With these additional costs, we expect that the supply of the fed cattle will be reduced, which will increase the price of fed cattle. Figures 1 and 2 show the changes in the price and quantities of fed cattle respectively. The percentage changes in prices and quantities are shown in table 13. With the added costs, the price of the fed cattle in 2010 is increased by 2.353% while the quantity is decreased by 2.249% in the same year. The impacts vary the same from 2010 to 2016.[10] In summary, with additional tagging costs, the model estimated a higher price and a lower supply of fed cattle. Theoretically, the increase in costs changes the primary and derived supply functions at the producer level, which leads to reduced supply and therefore increases the price. We observe it in our findings, making our results theoretically consistent. Intuitively, as the costs increase, a producer may add more heifers to their breeding stock (to get more benefits from the heifers and its progeny) resulting in a decrease in the supply of fed cattle and increase in price.

[10]The direction of the price and quantity remain the same from 2010 to 2016.

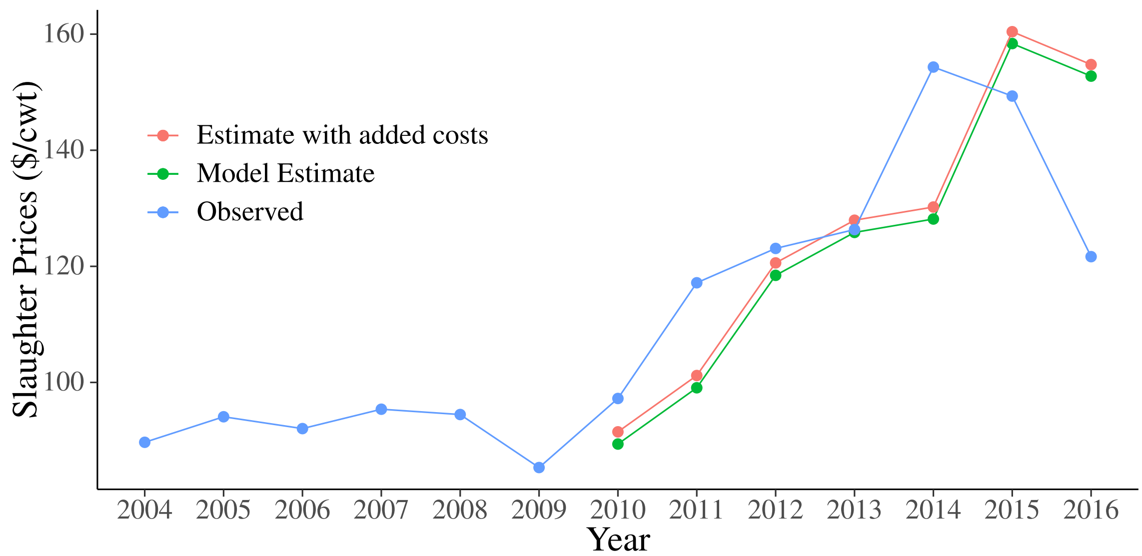

Figure 1: Observed, model estimate, & estimate with added costs of fed cattle price

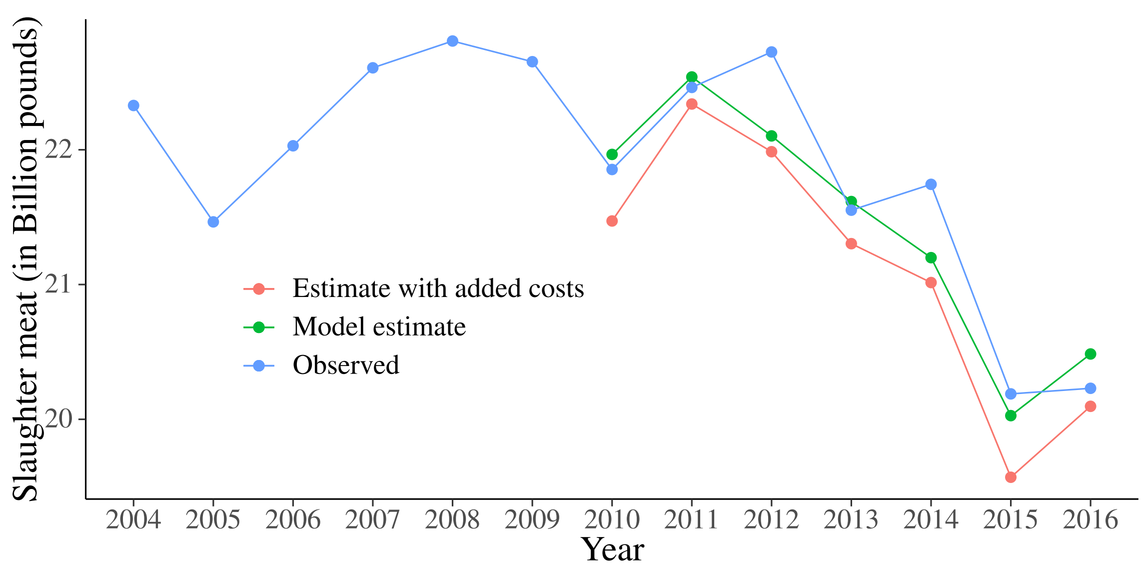

Figure 2: Observed, model estimate, & estimate with added costs of fed cattle meat

Table 13: Price and quantity percentage changes of fed cattle

Year	Δp_s	Δsl
2010	2.353	-2.249
2011	2.135	-0.890
2012	1.812	-0.531
2013	1.672	-1.446
2014	1.614	-0.872
2015	1.291	-2.283
2016	1.304	-1.895

Δp_s and Δsl denote percentage changes in price and quantity respectively.

The percentage changes in the price and quantities of cull cows are presented in Table 14. The graphical changes in the price and quantities for cull cows are showcased in figures 3 and 4 respectively. The costs of traceability program for cull cows in 2010 with full adoption are approximately \$0.332 billion. With the additional costs, the price and quantity of cull cows in 2010, increased by 5.102% and 17.571% respectively. With additional tagging costs, the supply of cull cows increased, although the price of cull cows increased. The percentage changes in price and quantity remain the same from 2010 to 2016. One way to explain this phenomenon is that the producer may cull the older or under-performing cows from the breeding stock thereby increasing the supply of the cull cows. Further, as the supply of the fed cattle has been reduced by the introduction of the traceability systems, in order to meet the demand, the supply of the cull cows should increase, which is captured by the model.

When interpreting the above results, it should be noted that the market share of fed cattle is relatively larger than the market share of cull cows. Our model captures the changes in the fed cattle markets with greater precision. However, the changes in the cull cow quantities are slightly higher. Along with the intuitive explanations given above, we also argue that the cull cow share in the market is small and can be considered a residual share, and the model captures this as residual share. Noting that, our results are theoretically and intuitively consistent, they constitute the expected changes from the traceability systems making them accurate.

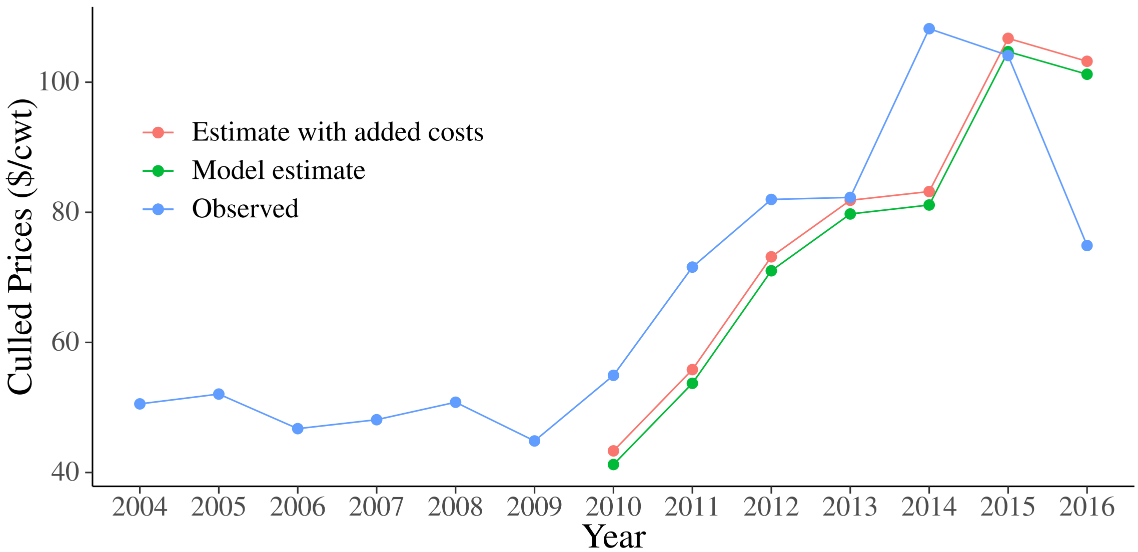

Figure 3: Observed, model estimate, & estimate with added costs of cull cow price

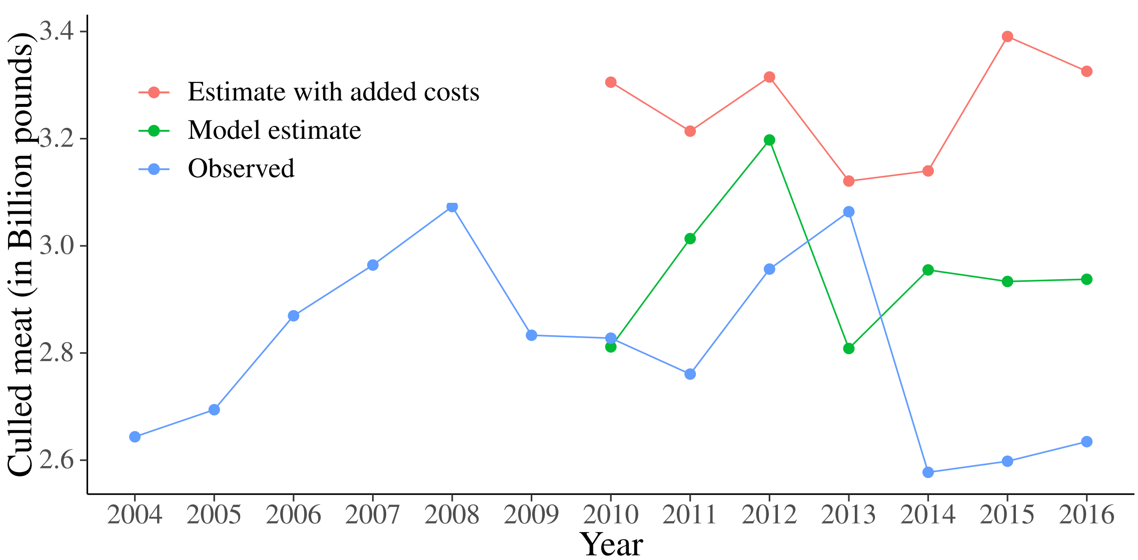

Figure 4: Observed, model estimate, & estimate with added costs of cull cow meat

Table 14: Price and quantity percentage changes of cull cows

Year	Δp_c	Δcl
2010	5.102	17.571
2011	3.938	6.657
2012	3.022	3.673
2013	2.639	11.126
2014	2.550	6.253
2015	1.953	15.588
2016	1.968	13.214

Δp_c and Δcl denote percentage changes in price and quantity respectively.

Using price and quantity changes, we quantify the change in the producer surplus. The producer surplus for each year with the introduction of the mandatory animal ID and traceability program is presented in table 15. With the mandatory traceability system in place, the aggregate change in producer surplus in 2010 decline by \$0.4655 billion. The direction of the change in the producer surplus remain unchanged from 2010 to 2016. Changes in the producer surplus with different adoption rates of animal ID and traceability system for the year 2010 are shown in figure 5. Since we assumed that demand would not increase, the losses in producer surplus increase and are linear with the animal ID adoption rates.

Table 15: Change in producer surplus (in billion dollars)

Year	ΔPS
2010	-0.4655
2011	-0.3373
2012	-0.2975
2013	-0.3515
2014	-0.3099
2015	-0.4581
2016	-0.4254

ΔPS denote change in producer surplus.

The long-run producer surplus changes of the traceability systems are calculated on the assumption that the prices and quantities will be adjusted after the short-run (1 year) impacts. We simulate the model with the short-run changes to see how the impacts vary over time. Over time, the

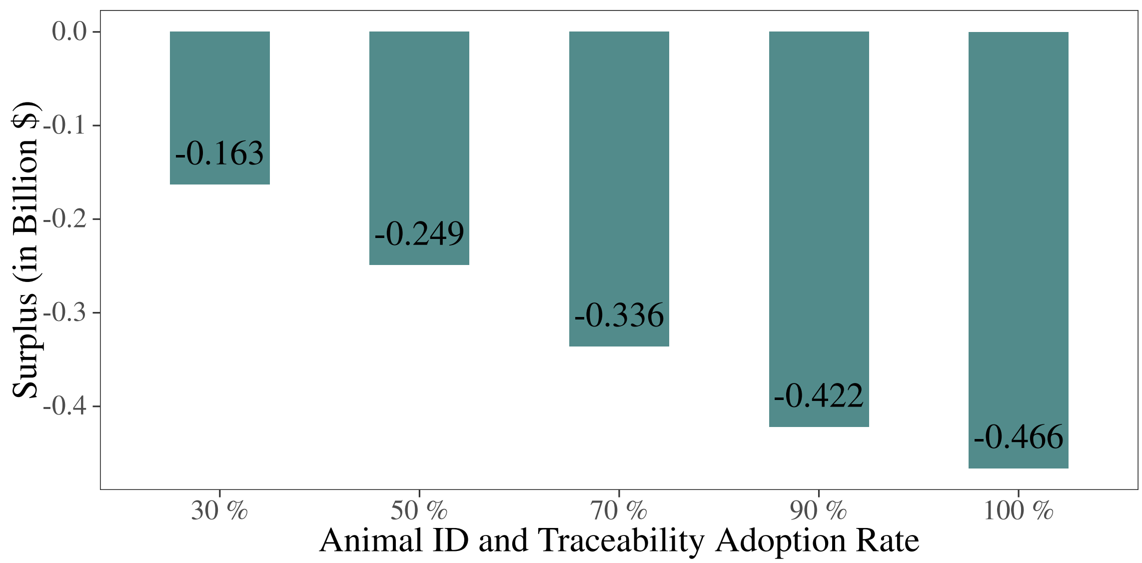

Figure 5: Producer surplus changes with different adoption rates

producer surplus losses decline. The aggregate change in short-run (one year) and long-run (seventh year) producer surplus is approximately $-\$0.4655$ billion and \$0.0250 billion, respectively.

All the above results are in consistent with previous studies, in particular, the direction of the impacts is similar to Pendell et al. (2010) and Pendell et al. (2013) studies. However, the magnitude of the impacts of our study is different from others. This is expected, because, the models used for estimating the impacts are different. Our model differentiates between the types of cattle (fed cattle and cull cows) and their associated prices. Our numerical analysis and results are strictly data-driven and are not based on simulated counterfactuals. The model parameters are dynamic and reflect the observed data. All of our results mimic the results of the literature which suggest that our model is suitable for policy analysis of the U.S. beef industry.

7.1 Impacts with cost-sharing for different adoption rates

One of the major obstacles for the producers to participate in the traceability systems is the associated increased costs. This is especially true for small operations.[11] Recent work by Mitchell et al. (2020) suggests that a simple instrument like *cost-sharing* that assists the producers with costs could

[11] For more information on how the costs depend on the size of the operation, see section 4.

encourage the producers and increase the participation in the traceability systems. Therefore, we simulate the model with different cost-sharing mechanisms for different adoption rates to determine the change in the aggregate producer surplus. The model is simulated with 20%, 30%, 50%, and 70% cost sharing for 30%, 50%, 70%, and 90% adoption rates. Table 16 presents the producer surplus changes for the combinations of cost-sharing and adoption rates for the year 2010. Under a 90% adoption to the traceability systems, with a 20%, 30%, 50%, and 70% cost-sharing, the producer surplus losses decline by 9.716%, 14.692%, 24.408%, and 34.123% respectively relative to no cost-sharing.

Table 16: Change in producer surplus (in billion dollars) with cost sharing for different adoption rates

	Cost Share			
Adoption Rate	20%	30%	50%	70%
30%	-0.147	-0.139	-0.123	-0.107
50%	-0.225	-0.213	-0.188	-0.164
70%	-0.303	-0.286	-0.254	-0.221
90%	-0.381	-0.360	-0.319	-0.278

Figures 6, 7, 8, and 9 illustrates the changes in producer surplus for 30%, 50%, 70%, and 90% adoption rates with various cost-sharing schemes for the year 2010.

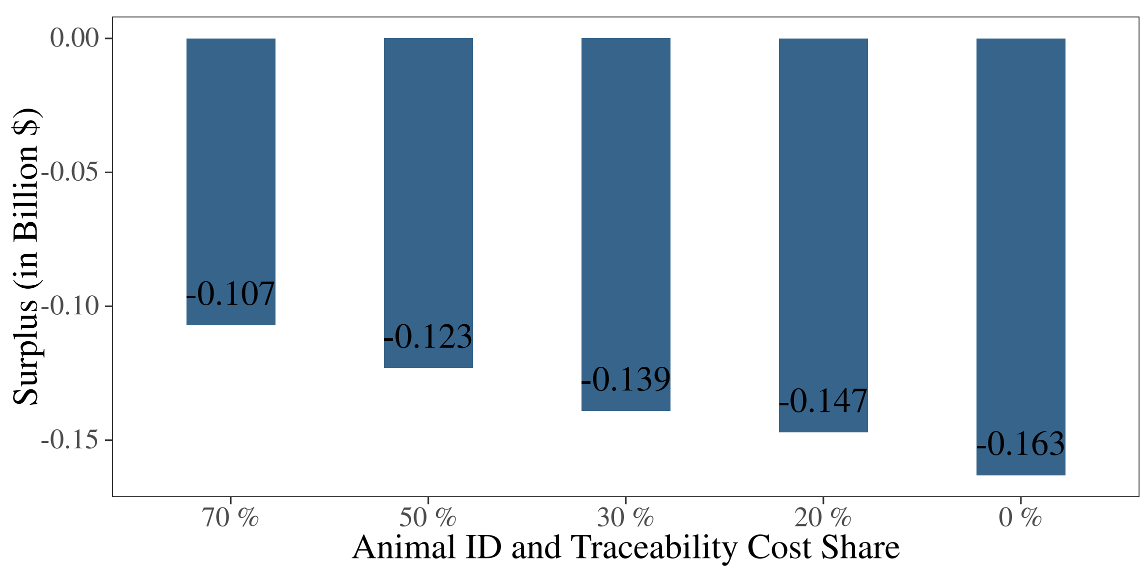

Figure 6: Producer surplus changes with 30% adoption rate for different cost sharing mechanisms

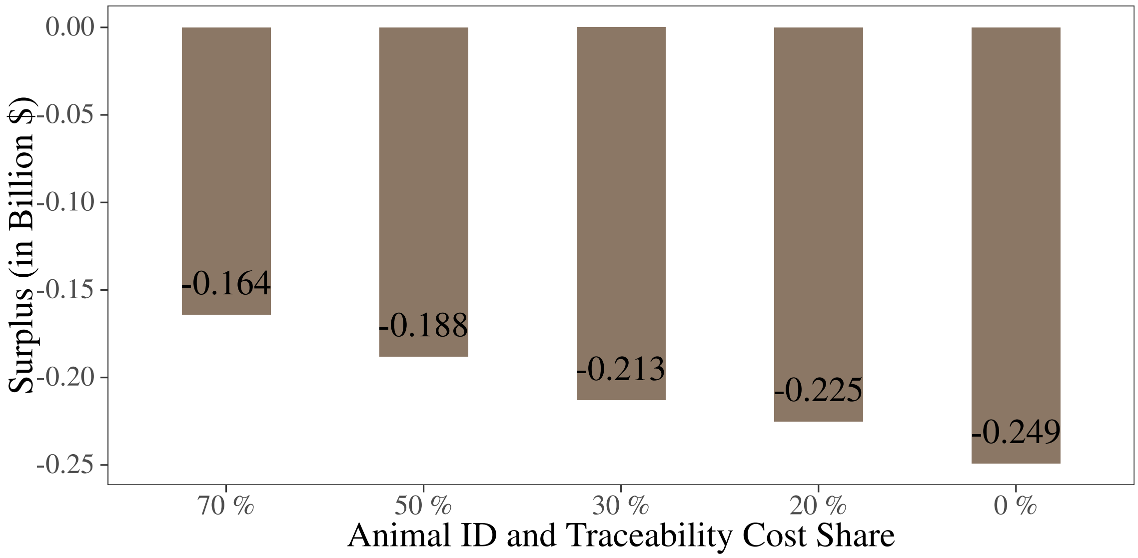

Figure 7: Producer surplus changes with 50% adoption rate for different cost sharing mechanisms

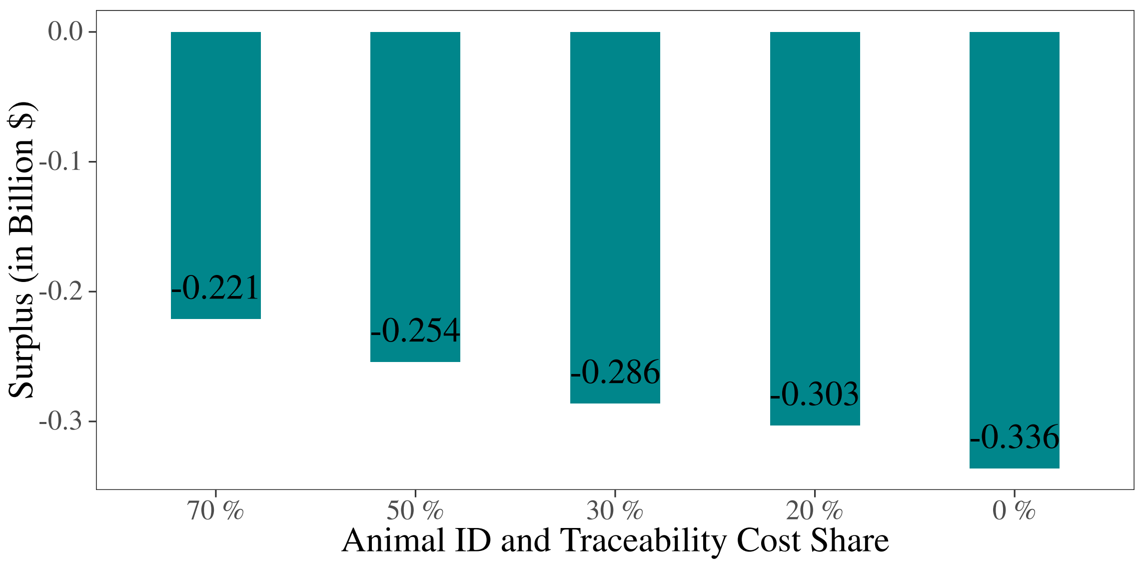

Figure 8: Producer surplus changes with 70% adoption rate for different cost sharing mechanisms

When it comes to introducing the cost-sharing instrument, one has to always ask a question how much of adoption rate is required and what cost-sharing scheme can achieve that adoption rate. A simple 20% cost-share might not guarantee a 90% adoption. It is important to know which cost-sharing scheme is appropriate to achieve a given adoption rate. In addition, all of our results show that the impacts are not the same every year and change every year. Knowing how the impacts

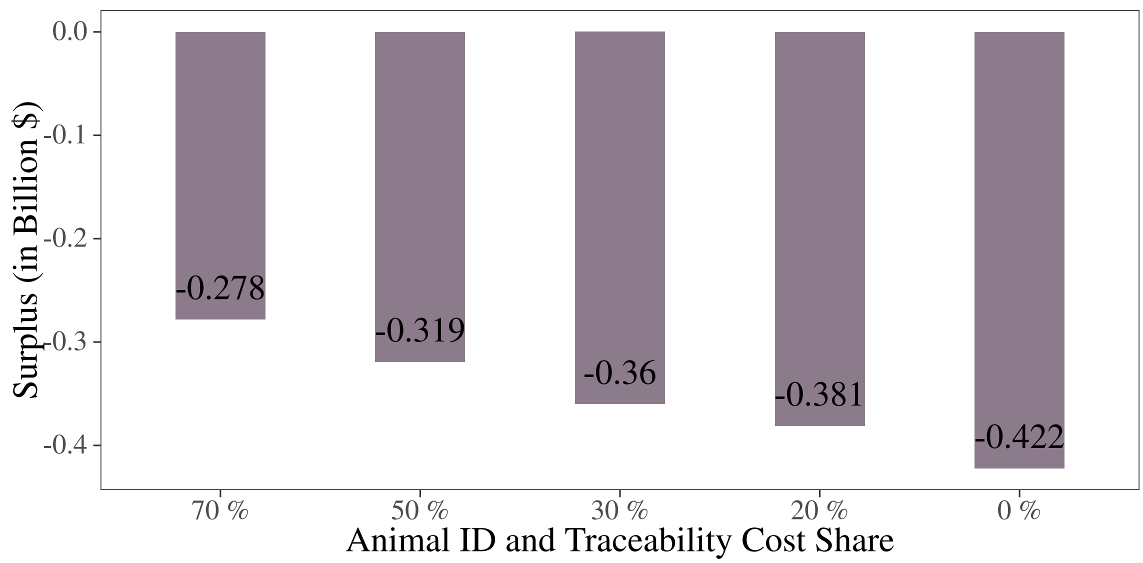

Figure 9: Producer surplus changes with 90% adoption rate for different cost sharing mechanisms

differ is important as this would help understand when and how a policy can be put in place to minimize producer surplus losses. When introducing / implementing a policy, timing is of the essence. An ideal policy should take into account the expansion and contraction of the stocks and determine when to increase/decrease the cost-sharing instrument in order to achieve greater adoption of traceability systems. For example, the current stock position of the herds, either at the peak or the trough, can be leveraged to establish/implement a policy instrument that benefits the beef cattle producers.

8 Summary and Conclusion

USDA APHIS efforts to increase participation in the traceability programs are encountering low participation and backlash, mainly due to the high costs of the system to the producers. Additionally, producers are concerned that the current system is too flexible, have too many exemptions, and inconsistencies in the regulation. A standardized national animal identification and traceability systems can address these problems, ultimately increasing transparency and protecting the domestic livestock.

In this study, we estimate the economic impacts of a mandatory animal identification and traceability system on the producers. Using a dynamic model of the U.S. beef cattle and rich cattle industry data, we quantify the change in producer surplus in short-run and long-run. In addition, we also show how the producer surplus changes over time. To the best of our knowledge, this is the first study to quantify changes in producer surplus over time. In addition, we estimate the producer surplus with different adoption rates.

Assuming no change in the demand, under complete adoption of the traceability system, in short-run (one year) the producer surplus would decline by $0.4655 billion. These losses are mainly due to the increased costs of traceability systems, changes in the prices and quantities of the fed cattle and cull cows. Assuming that the producers adopt to market changes with the system, we quantify the changes in the producer surplus over time. Over time, the producer surplus losses decrease and in long-run (seventh year), the producer surplus would be $0.0250 billion. The producer surplus losses increase as animal ID adoption increases and the relationship is linear.

All of our results are in line with Pendell et al. (2010) and Pendell et al. (2013). Especially the direction of the impacts. Given the differences in the models, the parameters, and methodology, the magnitude of our results cannot be directly compared to the results of Pendell et al. (2010) and Pendell et al. (2013). However, our model offers additional benefits, such as, parameters that are not fixed and move flexibly with the data, differentiate between the types of meat, and quantify how the impacts change over time.

In an attempt to increase producer participation in the traceability system, increasingly, the industry stakeholders and research studies are suggesting a simple *cost-sharing* tool that help the producers with costs. By simulating the model with different cost-sharing schemes under different adoption rates, we find that, under 90% adoption and with a 50% cost-sharing, the producer surplus losses would decline by 24.408%. When implementing a cost-sharing instrument, a one-time fixed cost-sharing may not achieve the target adoption. A close attention is required whilst introducing the cost-sharing instrument.

Based on our results, we find that timing is important when introducing/implementing any policy instrument in the beef cattle industry. In addition to accurately knowing what the short-run and long-run impacts are, knowing how they change over time can help the policymakers to get the timing of the policy correct. Along with short-run impacts, an ideal policy should take into consideration the long-run impacts, how the impacts vary over time, and whether the current inventories are in expansion phase or in contraction phase, eventually decreasing the producer losses.

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