Economics of Mandates on Farm Practices:

Lessons from Regulation of Pork Sold in California

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Regulations of food product availability tied to farm practices affect market prices, quantities, and welfare differentially. Impacts depend primarily on magnitudes of farm, processing, and distribution cost increases. However, particularly for processing and distribution, these costs depend on how much of the relevant market the regulations cover, and the costs of segregation in the supply channels. The product coverage of regulations also has major implications. Regulations may raise farm costs that apply to a subset of covered consumer products and other (non-regulated) products derived from the same farm output. We illustrate these principles with the important case of regulations on sales of pork products in California that are tied to mandates about how the breeding pigs are housed. The housing rules apply primarily to sows that farrow pigs that produce pork destined for California buyers. Two specific features of these regulations affect impacts: (a) California comprises about 10% of the North American pork market and it is costly to segregate the hogs and pork destined for California from the rest; and (b) the regulations cover only some of pork products from each hog. The result is that processing and distribution costs are higher for products covered by California regulation and competition implies that the cost increases must be borne fully by covered products. Simulations using realistic parameters show that: (1) compliant farrowing operations incur higher costs; (2) compliant processing and distribution operations incur higher costs; (3) covered pork products have higher retail prices reflecting these costs; (4) with higher prices, California consumers of covered pork products have substantial welfare losses; (5) impacts on non-covered prices and quantities are very small; and (6) impacts on consumers outside California are very small.

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1. Introduction

This paper studies the economic implications of regulations on farming practices. Farming practices often have been studied in the context of productivity improvement or environmental pollution reduction. However, in recent years, there have been a series of government mandates, labeling rules, and food supplier adjustments that address a variety of social and environmental claims about food production (Sumner et al., 2008; Saitone, Sexton, and Sumner, 2015; Saitone and Sexton, 2017; Mullally and Lusk, 2018). Some states, including California, also have introduced laws to impose restrictions on products allowed to be sold based on farming practices. This paper focuses on such farming-practice regulations.

Recent regulations limit both farming practices and sales of related products within a jurisdiction. When regulations cover only local farming practices in markets that are open to outside competition, that clearly disadvantage local producers, perhaps with little effect on farm practices (Sumner et al., 2010). Local farm practice regulations alone may result in a change in production location rather than a change in production practices, costs, prices, or quantities. The obvious approach is for regulations that require all the products sold in a jurisdiction to satisfy farming practice standards.

Regulating product sales based on farming practices is complicated. Farms typically supply raw materials for processors or distributors. Processors and distributers produce and supply consumer products, and wholesalers supply them to retailers and food-service providers. For example, farms supply finished hogs to processors that supply meat products. Meat manufacturers further process and generate final meat products such as pork cuts, sausages, hams, and other more heavily processed products that may be combined with other ingredients for related food products and meals (for example, sandwiches, pizzas, and soups). The variety of

food products has widened as the food supply chain has developed to satisfy the demand of consumers who value many attributes in food purchase and consumption (Saitone and Sexton, 2017). It adds complexity to implement regulations as the number of final products increases.

Regulators choose a range of regulated products, considering costs of implementation actions such as certification, record keeping, and monitoring. They also must clarify the definitions of regulated food products.

This paper develops the economics of these issues using the case of regulations on pork sold in California. In 2018, California passed Proposition 12 (Prop. 12). Prop. 12 requires, for some pork products sold in California, farms to allow breeding pigs at least 24 square feet of usable floor space per pig starting in 2022. Prop. 12 characterizes those regulated products to be uncooked and unmixed with other ingredients. Regulation has developed much more detailed definitions of covered products. Our research considers several scenarios about the implications of alternative definitions.

We construct an economic model of the North American pork industry, covering both the United States and Canada. The model describes hog production, processing, marketing, retailing, and foodservice. Given the base available estimates of cost compliance at each stage, the model projects changes in pork prices, production and consumption of pork products, and consumer welfare due to Prop. 12.

Simulation results show that: (1) compliant farrowing operations incur higher costs; (2) compliant processing and distribution operations incur higher costs; (3) covered pork products have higher retail prices reflecting these costs; (4) with higher prices, California consumers of covered pork products have substantial welfare losses; (5) impacts on non-covered prices and quantities are very small; and (6) impacts on consumers outside California are very small.

The rest of this paper is organized as follows. Section 2 describes California's sow housing regulations. Section 3 outlines the North American pork supply chain. Section 4 explains farm cost increments by Prop. 12. Section 5 explains the processing and marketing cost increments by Prop. 12. Section 6 describes the economic modeling of the North American pork industry. Section 7 reports simulation results. Section 8 reports conclusions.

2. California's Sow Housing Regulations

Proposition 12 was approved in November 2018, with more than 60% of Californians voting in favor. According to Prop. 12, California farms "shall not knowingly cause any covered animal to be confined in a cruel manner." Covered animals include egg-laying hens, breeding sows, and calves raised for veal, and this paper focuses on breeding sows. In terms of breeding sows, "confined in a cruel manner" means that "confining a breeding pig with less than 24 square feet of usable floor space per pig." An exception holds to a breeding pig "during the five day period prior to the breeding pig's expected date of giving birth, and any day that the breeding pig is nursing piglets" (text in Proposition 12, Section 25992 of the California Health and Safety Code).

In addition to the above sow housing regulations, Prop. 12 regulates sales of related products. According to Prop. 12, "a business owner or operator shall not knowingly engage in the sale within the State of California of any whole pork meat that the business owner or operator knows or should know it the meat of a covered animal who was confined in a cruel manner, or is the meat of immediate offspring of a covered animal who was confined in a cruel manner." Business owners and operators include intermediary agents in the pork supply chain to the California market, including slaughter plants, processors, wholesalers, retailers, and food-service

providers. The definitions of "confined in a cruel manner" and covered animals are identical to those in the previous paragraph (text in Proposition 12, Section 25992 of the California Health and Safety Code).

As we discussed in the Introduction, we need to specify which pork products are regulated to complete the sales regulations. Prop. 12 denotes those regulated pork products as "whole pork meat" and defines "whole pork meat" as follows: "Whole pork meat" means "any uncooked cut of pork (including bacon, ham, chop, ribs, riblet, loin, shank, leg, roast, brisket, steak, sirloin or cutlet) that is comprised entirely of pork meat, except for seasoning, curing agents, coloring, flavoring, preservatives and similar meat additives." The term, "uncooked," means "requiring cooking prior to human consumption." To clarify the definition of "whole pork meat," Prop. 12 characterizes unregulated pork products and provides examples. "Whole pork meat does not include combination food products (including soups, sandwiches, pizzas, hot dogs, or similar processed or prepared food products) that are comprised of more than pork meat, seasoning, curing agents, coloring, flavoring, preservatives, and similar meat additives" (text in Proposition 12, Section 25992 of the California Health and Safety Code).

Although Prop. 12 specifies regulated pork products, Prop. 12 does not characterize a fully detailed list of products to eliminate potential ambiguity. Therefore, the California Department of Food and Agriculture (CDFA) regulators proposed more specific regulations.[2] However, those proposed regulations are not yet finalized. Sumner et al. (2020) give a good summary of the proposed regulations.[3]

[2] The document (Draft Article 3. Pork Meat) on the proposed regulations are available at the following website: https://www.cdfa.ca.gov/ahfss/Prop12.html.
[3] The document is available at the following website: http://www.dof.ca.gov/Forecasting/Economics/Major_Regulations/Major_Regulations_Table/documents/CDFA_Proposition_12_SRIA.pdf.

Hence, we consider two scenarios on the list of regulated pork products. First, ground pork is not regulated. Second, ground pork is regulated. Based on the 2018 US retail market sales data provided by the National Pork Board, about 58% of pork products are regulated by Prop. 12 when ground pork is not regulated. However, about 77% of pork products are regulated when ground pork is regulated. We use those two scenarios to illustrate how important specifying the list of regulated products will be on the regulations' economic effects.

3. The North American Pork Supply Chain

Hog production and marketing in North America have changed over the past 25 – 30 years. Whereas in the early 1990s, over 90% of market hogs were transacted for cash prices in auction markets, today, almost all hogs are transacted through production or marketing contracts (MacDonald et al., 2018). Under production contracts, primary processors have ownership of market hogs throughout all the stages of a hog's life cycle. Hog producers provide buildings, labor, and management, while primary processors provide hogs, feed, and medicine. However, under marketing contracts, producers have the ownership until hogs are finished, and primary processors buy finished hogs based on pricing arrangements.

The first stage of hog production is the farrowing stage, where breeding sows produce piglets. Breeding sows feed piglets for about the first 21 days of life. Prop. 12 applies at the farrowing stage, with the minimum 24 square-foot space requirement per sow. However, the minimum space requirement does not apply during the five days before the birth of piglets and the period when piglets remain with the breeding sow after birth.

According to our discussions with farmers and other industry members, most farrowing farms plan to adopt group housing to satisfy the minimum space requirement. Currently, most

farms use gestation stalls (or often called gestation crates) for breeding sows. Farms confine each breeding sow in each gestation stall whose space is too small for breeding sows to move around, which violates the minimum space requirement of Prop. 12. Contrary to gestation-stall housing, under group housing, breeding sows can move around and meet each other.

Some farrowing farms have already implemented group housing or are in the process of implementing group housing. Those farms will have a cost advantage in compliance with Prop. 12, relative to other farrowing farms that use stall housing for breeding sows. However, our research indicates that few sows are currently housed in compliant ways with Prop 12's space requirements. Hence, any farrowing farm which plans to produce Prop. 12-compliant hogs will face substantial one-time costs to convert facilities and higher ongoing variable costs. We will discuss these compliance costs further in the following section.

After weaning, piglets (sometimes called weanlings) are transferred to nursery operations for 6 – 8 weeks, at which time those pigs reach a weight of 50 – 60 pounds. Afterward, pigs are moved to a finishing operation where those pigs are fed a diet of corn and soybean meal and nutritional supplements for a period of 115 – 120 days. When pigs are ready for the market at the end of this stage, pigs reach a weight of 270 – 300 pounds.

Prop. 12 will have a little direct effect on nursery and finishing operations. However, the nursery and finishing operations will face a higher price of the California-compliant pigs from compliant farrowing operations. Those compliant pigs do not require special treatment. However, those pigs must have their identities preserved to be segregated before the next marketing and slaughter stage.

These three stages of a hog's development often take place within one integrated operation. Alternatively, pigs are transferred to a separate nursery operation and fed under either a production- or marketing-contract arrangement.

Primary processors acquire market hogs mainly from their contract growers. However, primary processors sometimes acquire additional hogs through residual spot markets. Primary processors undertake slaughter and dressing operations and produce the main cuts of pork and sausage. These products are sold to wholesalers, retailers, and food-service operators, or secondary processing operations. These secondary processing operations produce processed products, including lunch meats, hams, and specialty sausages such as chorizo, salami, brats, and hotdogs.

Both primary and secondary processing operations will face higher costs to produce pork for the California market under Prop. 12. Because most of these operations will produce non-compliant pork for the rest of the United States, they will have to implement segregation protocols to isolate Prop. 12 hogs or pork from hogs and pork that is not compliant. Such operations will also have to undergo costly compliance audits and undertake processes to ensure that their suppliers are compliant. For example, operations selling products to retailers will have to create new stock-keeping units (SKUs – the scannable barcode) for compliant products, which results in an additional fixed cost. If offerings of pork products in California remained as varied as before Prop. 12, those processors would need to double their number of SKUs approximately. In the context of the country of origin labeling, studies provide evidence that those additional costs for segregation along the supply chain would be significant (see Sumner and Zuijdwijk, 2019, in the country of origin labeling). Based on those findings, we assess additional processing and marketing costs by Prop. 12.

Wholesaling and retailing operations likely face higher costs under Prop. 12. The cost increase would come mainly from segregating compliant products in trucks and warehouses that served outlets in multiple states for ensuring traceability of products and suppliers who comply with Prop. 12. These cost increments will be specific to the logistical operations of retail chains and wholesalers. Based on discussions with industry members, we could obtain little direct information on these costs' likely magnitude. Hence, we concluded that these cost increments would play no part in our analysis.

4. Costs to Farrowing Operations of Compliance with Proposition 12

To understand the implications of Prop. 12 for the pork industry and understand how the industry will adjust, we must assess the costs of producing and marketing pork products compliant for sales in California under the Prop. 12 rules compared to costs without the Prop. 12 rules. We gathered data from producers and processors' written surveys and several in-depth telephone conversations with participants throughout the pork supply chain. We chose those survey participants for their expertise on costs associated with converting operations to Prop. 12 compliance.

We consider the costs of Prop. 12 compliance compared to group housing costs. Given the California pork market's size, about 8.5% of North American pork production will need to meet Prop. 12 standards. About 30% of North American sows currently in group housing (about 2.2 million sows in the United States and Canada). Most existing farrowing operations of group housing do not satisfy the minimum space requirement of Prop. 12 (24 square feet per breeding sow). Interviews with producers confirmed the relevance and applicability of the incremental costs for those currently using group housing for breeding sows. Hence, the one-time cost of

conversion, we consider here, applies to farrowing operations, which either now have group housing or would be otherwise establishing standard (non-compliant) group housing. We also compare ongoing operating costs for compliant group-housing operations with non-compliant group-housing operations.

Background about categories of costs

We consider the one-time cost of conversion and the additions to annual variable costs of operation both. The one-time conversion cost depends on the operation's size, and the additional variable cost is often on a per hog basis.

The conversion costs can be considered one-time costs. However, the conversion costs can recur periodically in the added facility and employee training costs. We can also interpret the conversion costs as the sum of regular payments by installments in capital recovery costs. Hence, the conversion costs can be considered variable costs over the policy change's decision horizon and can increase the average and marginal costs per pig and pound.

Some of the additions to the annual cost of operations could be fixed costs. Some additional variable costs could be independent of the operation size and quantity of weanling pigs marketed. However, we will again consider the regulatory change horizon long enough such that all operating costs are considered a part of variable costs. That is, the marginal cost per pig rises with all added costs from the regulation.

Data and estimates of impacts of compliance with Proposition 12 on on-farm costs

We consider the costs per sow, per weanling pig, and per marketable pound of pork and the category of uncooked cuts of pork that must be Prop. 12 compliant. To meet projected California

demand, about 0.7 million sows would need to be kept in housing that has been built or converted to be compliant with Prop. 12.

Let us first consider the increase in capital recovery and related fixed costs per sow of meeting Prop. 12 standards for breeding sows currently in group housing. These costs differ across operations because the existing group housing facilities differ in the amount of space they provide, the technology they use for feeding, the amount of time they now keep sows in stalls after farrowing, and the number of sows they move to stalls for health or behavior concerns during gestation.

On average, capital recovery costs accounted for about 12% to 15% of total production costs of US farrow-to-wean operations in 2014, according to USDA data, which is not differentiated by sow housing type. The Ontario Ministry of Agriculture, Food and Rural Affairs reported that fixed costs (can be interpreted as capital recovery costs) accounted for about 19% of total costs in early 2019. However, we expect that 19% would be greater than the usual share of capital recovery costs in total costs because 2019 was a low feed-cost year. Based on the review, we expect that the capital recovery costs would be about 16% of total costs, which is our base in the analysis.

Capital costs include facility costs and new equipment costs. Facility costs per sow rise by about 20% because farms reduce breeding sows to increase space per sow from 20 to 24 square feet. Adopting new electronic feeding and other innovations likely add another 5% to capital costs. Hence, given that the capital recovery costs account for about 16% of total costs, the farm cost increase is about 4% of total costs.

Variable costs include feed, labor, other intermediate input costs. Feed costs account for about 50% of the total costs of producing weanling pigs. Other variable costs, including labor, veterinarian services, and medicine costs, account for 34%.

Feed costs rise mainly because of an increase in breeding sow mortality and a decrease in breeding efficiency. Specifically, breeding sow mortality likely rises by about 2%, which partly results in an about 12% decrease in the number of weaned pigs per sow. Breeding efficiency falls primarily because farms cannot use gestation stalls by Prop. 12. Overall, breeding sow feed costs per marketed weanling pig will rise by about 12%, which contributes a 6% increase in total costs per pig.

Other variable costs will rise by about 15% because of spreading costs across fewer weanling pigs and because of the need for more labor and health care per sow. Those additional variable costs will add about 5% to total costs per pig.

Combining the three categories, such as capital recovery costs, feed costs, and other variable costs, we obtain a (4% + 6% + 5% =) 15% increase in total costs per weanling pig for converting operations. Using an average cost of about $33 per weanling pig, we obtain a cost increment at the farrowing operation of about (0.15 * $33 =) $5 per weanling pig.

The 15% increase in weanling pig costs is consistent with the data from our correspondents and interviews. Considering that weanling pigs grow up to finished hogs and that little additional costs will occur in the finishing stage, the cost of $5 per weanling pig implies the cost of about $3 per hundredweight of carcass meat available for retail sales. Considering that finished hog weights about 160.8 pounds, on average, the cost of $5 per weanling pig also implies a $5 increase per retail weight of 160.8 pounds of pork per pig.

Now let us consider how these compliance costs are likely to differ across compliant farms. Firms compete in the market for pork from breeding sow farms using group housing. Hence, those that remain in that market have comparable costs, and farm-specific costs are attributable to some farm-specific characteristics that differ across farms. For example, some farms perhaps have lower costs because of managerial expertise for which the farm earns higher profits. Some other farms possibly have some unique attributes that allow them to earn higher profits than their peers in the market.

One way to model the range of farms, which is the distribution of costs, is to treat $5 per head as roughly the midpoint of the uniform distribution of costs. If we take the range from $4 per head to $6 per head, this range is equivalent to the percentage increase in marginal costs per weanling pig of between about 12% and 18%.

It is important to recognize that this range's operations represent the low end of farms in compliance costs. About 80% of pigs are weaned on operations that would have more costs than $6 per weanling pig and would not consider converting, given their high costs relative to other efficient farms. Hence, those inefficient farrowing operations are not relevant to the calculations.

5. Additional Costs of Processing and Marketing Proposition 12 Compliant Pork

The weanling pigs that leave farrowing operations at about 13 to 15 pounds move through the feeding stages to reach slaughter weights of between about 270 and 300 pounds. Under Prop. 12, any of these finished hogs destined for the California market must be identified. Specifically, the uncooked and unmixed pork cuts from these compliant hogs must be segregated and labeled through all the supply chain stages.

Since pigs from the compliant farrowing operations are more costly than non-compliant ones, any feeding operation would maintain these hogs' added value by marketing them separately at a higher price that reflects their added costs. Besides keeping identity preserved, there is little difference in how these hogs are housed or fed. Hence, any added costs during the feeding stages are small on a per-hog basis. The compliant hogs will be sold at higher prices per hog that reflect the added costs.

Primary processors acquire finished hogs from finishing operations and produce pork products, including uncooked cuts of pork such as bacon, chops, roasts, ribs, and others. Primary processors also produce pork used for cooked products such as lunch meats and fully cooked hams. Furthermore, they produce pork used as ingredients in prepared foods such as hotdogs or pizza. They also sell pork used in uncooked mixed products such as soups and meat mixtures.

We expect that many primary processing operations will not bother to adjust to Prop. 12 rules. Compliant hogs will account for only about 8.3% of total hogs, so many processing operations would choose not to supply the California market with compliant pork products. Those operations will then not have added costs of identifying, segregating, tracing, and labeling the compliant pork separately from their production's non-compliant pork.

Some primary processing operations will adjust to Prop. 12 rules. Those operations will acquire compliant finished hogs and compliant uncooked cuts of pork to the California market. Those operations will have additional costs to ensure that they can sell this compliant pork into the California market. Specifically, pork destined for compliant uncooked cuts of pork must be identified, segregated, and traced. Given the realities of processing, about 8.3% of compliant hogs will need to be segregated and processed in groups at different times from other hogs to

ensure that no non-compliant pork intermingles with fresh pork products destined for the California market.

Based on discussion with pork processors, we understand that plants likely designate the first part of certain days each week to process compliant hogs. The reason to start is to assume no non-compliant pork remains on the line at the beginning of the day. Starting at the beginning of the day, plants would avoid such situations that compliant pork products inadvertently commingle with non-compliant pork. Furthermore, plants do not need to clean the processing line in the middle of processing, saving time. Starting at the beginning of the day minimizes the chance of mistakes and reduces disruption time.

If plants with about 42% of the total processing capacity in North America handled some compliant hogs, which means, those plants would devote about 20% of their processing time to processing the Prop. 12 compliant hogs. For example, for plants that operated five days per week, devoting the first 25% of each day on four days per week to Prop. 12 compliant hogs would equal 20% of the whole production in the week. This sort of schedule would reduce the problems that hogs might spend several days, which is too long in finishing operations, or get slaughtered too soon, which would happen if a plant only processed compliant hogs on a single day each week. However, inevitably, there will be added transport and scheduling costs of a limited processing schedule. Hence, we expect that only some plants will accept compliant hogs, and these costs will account for a proportion of the price of compliant pork.

For compliance, plants must have separate holding pens, more complicated and less flexible schedules, interruption in plant operation between processing compliant and non-compliant hogs, additional storage capacity to keep compliant pork separately from non-compliant pork, a more complicated labeling process, and more complex shipping of labeled

products. All of these added procedures have costs, and the costliest of these procedures is likely to be the interruption of plant operation during the change-over from compliant to non-compliant hogs and pork. This interruption means lower throughput on days that compliant hogs are processed. Our best estimate is that the additional cost is about $15 per compliant hog slaughtered based on industry information and additional data.

This cost estimate would apply to the uncooked pork from compliant hogs. Uncooked pork accounts for about 58% of the retail meat if uncooked pork does not include ground pork and uncooked sausages. However, uncooked pork accounts for about 77% of the retail meat if uncooked pork includes ground pork and sausages. Given 160.8 pounds of a finished hog weight, on average, the cost estimate would apply to 93 pounds per hog if 58% of the retail meat is in the uncooked cuts of pork category and about 124 pounds per hog if 77% of the retail meat is in the uncooked cuts of pork category. For the 58% alternative, the added cost is ($15/93 =) $0.16 per pound of compliant pork. For the 77% alternative, the added cost is ($15/124 =) $0.12 per pound of compliant pork. These costs add to the retail price of uncooked cuts of pork in California. We reflect the added costs as a 5% increase in aggregate marketing costs from farms and retailers.

In addition to higher costs at the primary processing plants, there will be additional costs for handling compliant pork throughout the downstream marketing chain. Based on our survey and information from secondary processors and marketers, we estimate these costs to be about $0.05 per pound of compliant uncooked cuts of pork.

Overall, we estimate the segregation, identity preservation, traceability, and other compliance costs such as audits and registration to be about $0.21 per pound of compliant pork products under the case when 58% of each hog is used for compliance-required products.

Similarly, we estimate those costs to be about $0.17 per pound when 77% of each hog is used for compliance-required products.

We note that a small part of the total pork sold derives from culled sows at the end of their cost-effective life as breeding sows. Considering that a sow produces more than 50 piglets that grow to market hogs, the sow contribution is about 2% of hogs marketed in North America. These sows are not used primarily for uncooked pork cuts, and we assume that culled sows enter the North American market for cooked pork products, although we recognize that some portion possibly goes into fresh pork sausage. We assume that few sows enter the market for compliance fresh pork because mother sows of those culled sows have needed to be housed according to Prop. 12 rules.

6. Economic Simulation Modeling the North American Hog-Pork Industry

We develop an economic model to simulate the likely effects of the regulations by Prop. 12. Specifically, we characterize market outcomes with and without those regulations. Our simulation model explicitly describes multiple stages in the food supply chain (Freebairn, Davis, and Edwards, 1982; Wohlgenant, 1993; Saitone, Sexton, and Sumner, 2015). Among existing studies, Saitone, Sexton, and Sumner's (2015) approach is most similar to our approach.

Our model assumes a fixed-proportions relationship between quantity, Qf^S, of live hogs supplied at farm and quantity, Qr^S, of pork products supplied at retail and foodservice for a given period, which is one year for concreteness. We write farm-to-retail product conversion as $Qr^S = Qf^S \cdot \alpha$, where the parameter, α, is the factor for converting live hog quantity into the quantity of retail pork products. This conversion factor is about $\alpha = 0.57$, given the fact that a finished hog provides about 160.8 pounds of retail pork. We dispense with the conversion factor,

α, through proper measurement units, namely by measuring live hogs in their retail weight equivalent.

We first derive a market equilibrium in the but-for world where Prop. 12 was not passed and then compare it to the market equilibrium in the presence of Prop. 12. The difference in outcomes between these two market equilibria enables us to simulate the impacts of Prop. 12 on prices, outputs, producer profits, and consumer welfare.

Farm (primary) supply of market hogs

We consider an integrated live-hog production chain from farrowing piglets to finishing hogs. Individual hog producers are depicted in terms of supply functions, $Q_i = g_i(Pf)$, where Pf denotes farm price per hog in retail weight equivalent, and Q_i denotes the output of the i producer. We obtain the market supply of hogs by summing outputs over producers. We express the primary supply of market hogs as a linear function in its inverse form as follows:

$$Pf^S = a + b \cdot Qf^S.$$

The term, Qf, denotes live quantity in retail weight equivalent, and the superscript, S, denotes a supply relationship.

In calibration, we solve for the intercept, a, and the slope parameter, b, of the supply function such that the function fits the most recent available market equilibrium values for North American hog production, which is 2018, based on Canadian and US government statistics. We complete the hog supply function's calibration by assuming a value for the price elasticity of supply of hogs, given 2018 equilibrium values. We assessed the supply elasticity of hogs to be about 1.8. The assessed value is consistent with a range of estimates suggested and used by

existing papers studying the U.S. pork industry (Lemieux and Wohlgenant, 1989; Wohlgenant, 1993; Brester, March, and Atwood, 2004; Saitone, Sexton, and Sumner, 2015).

Final consumer demand for pork products

A hog carcass produces many pork products, and foodservice providers serve many meals with pork as ingredients. However, for our research purposes, it suffices to aggregate those products into two categories for the North American market: uncooked (fresh) pork and cooked pork products. Cooked pork includes pork mixed with one or more other ingredients. Prop. 12 regulates sales of uncooked pork but does not regulate sales of cooked pork. Prop. 12 does not give a fully specified list of regulated products, and there is an ambiguity on whether uncooked pork includes ground pork. Hence, in simulations, we consider two scenarios based on whether uncooked pork includes ground pork.

We specify inverse final demand for uncooked pork and cooked pork for the North American market in a linear form:

$$Pr_F^D = \gamma - \beta_o Qr_F^D - \beta_c Qr_N^D,$$

$$Pr_N^D = \theta - \eta_o Qr_N^D - \eta_c Qr_F^D.$$

The superscripts, D, denotes a demand relationship. The subscripts, F, denotes uncooked pork, and the subscript, N, denotes cooked pork. The term, Pr, is the price at retail, and the term, Qr, is sales volume at retail and foodservice. These specifications allow substitution by consumers between uncooked pork and cooked pork products, depending on the cross-product coefficients, β_c and η_c, in the equations.

To calibrate the demand functions, we began with a base price elasticity of demand for all pork from Okrent and Alston (2011, 2012). Okrent and Alston (2011, 2012) estimated a retail

price elasticity of demand of -0.68 for all pork. Compared to the demand for all pork, the demands for uncooked and cooked pork will be more price elastic, based on the expectation that consumers are willing to substitute between uncooked and cooked pork products in response to changes in their relative prices. Based on our review of the relevant literature (Wohlgenant and Haidacher, 1989; Buhr, 2005; Okrent and Alston, 2011, 2012), we chose a base value of -0.9 for uncooked pork and -1.1 for cooked pork. Given the -0.68 estimate of the price elasticity of demand for all pork and the market shares, the implied cross-price elasticity is 0.36 for cooked pork demand in response to a change in the price of uncooked pork. Similarly, the implied cross-price elasticity is 0.26 for uncooked pork demand in response to a change in cooked pork price.

Analogous to the procedure used for calibrating the farm supply function, we solved these demand functions for the intercept and slope coefficients. Specifically, the demand functions go through 2018 base-year values for the disappearance of and price for uncooked and cooked pork and, at the same time, have those above own- and cross-price elasticities of demand at these based equilibrium points.

Pork processing and marketing sector

Pork processors take live hogs and convert them into uncooked pork and cooked pork. Uncooked pork and cooked pork products are sold downstream to wholesalers, secondary processors, foodservice operators, and grocery retailers.

Consistent with prior work, we assume that all marketers (wholesalers, retailers, and foodservice operators) operate with constant per-unit costs. We also assume that pork processing, wholesaling, and retailing are performed under perfectly competitive conditions (for example, Saitone, Sexton, and Sumner, 2015). Let the parameters, c_F and c_N, denote the unit costs of

processing and marketing uncooked pork and cooked pork from farm to retail or food service. We computed the values for c_F and c_N, based on the 2018 USDA data on the average farm price for the retail weight of market hogs and data provided by the National Pork Board for the average retail price of cooked and uncooked pork. These calculations yielded c_N = \$250.8 per hundred pounds of retail weight and c_F = \$99.8 per hundred pounds of retail weight. Then, we obtain the relationship between hog price at farm and pork prices at retail as follows:

$$Pf^D = \frac{Qf_F^S}{Qf^S} \cdot Pf_F^S + \frac{Qf_N^S}{Qf^S} \cdot Pf_N^S, \text{where}$$

$$Pf_F^S = Pr_F^S - c_F,$$

$$Pf_N^S = Pr_N^S - c_N.$$

The term, Pf_F^S, is the remainder of retail uncooked pork price minus per-unit retailing costs of uncooked pork. The term, Pf_N^S, is the remainder of retail cooked pork price minus per-unit retailing costs of cooked pork. The term, Pf^S, is the finished hog price at farms, which is the average of the two terms, Pf_F^S and Pf_N^S, weighted by their quantity shares.

We assume that processors can choose proportions of uncooked pork and cooked pork from a hog carcass. However, we expect that these two types of pork products are not perfectly transformable into each other because of at least two reasons. First, processing facilities for uncooked pork differ from those for cooked pork, and it would be costly to transform different types of facilities into each other. Second, characteristics differ across parts of a hog carcass, and some parts would be more appropriate for uncooked pork than cooked pork (or more appropriate for cooked pork than uncooked pork).

Under the assumption of a constant elasticity of transformation, the transformation between uncooked pork and cooked pork is depicted as follows:

$$Qf = B \cdot (\alpha \cdot (Qf_F)^{\rho} + (1-\alpha) \cdot (Qf_N)^{\rho})^{\frac{1}{\rho}}.$$

The variable, Qf, is the quantity of finished hogs at the retail equivalent weight. The variable, Qf_F, is the quantity of slaughtered pork used for uncooked pork. The variable, Qf_N, is the quantity of slaughtered pork used for cooked pork. The term, B, is the scale parameter of the transformation function. The term, α, is the share parameter of the transformation function. The term, ρ, is the elasticity parameter, which is $1 < \rho < \infty$.

Let us assume that processors take prices as given. Then, given the specified transformation function and the revenue maximization assumption, the supply functions of uncooked pork and cooked pork as follows:

$$Qf_F^S = \frac{Qf^D}{(B)^{1+\sigma}} \cdot \left[\frac{Pf_F^S}{\alpha \cdot Pf^D}\right]^{\sigma},$$

$$Qf_N^S = \frac{Qf^D}{(B)^{1+\sigma}} \cdot \left[\frac{Pf_N^S}{(1-\alpha) \cdot Pf^D}\right]^{\sigma}.$$

The superscript, *S*, denotes a supply relation. The term, σ, is the constant elasticity of transformation such that $0 < \sigma < \infty$. Before Prop. 12 rules are implemented, it is uncertain how flexibly pork processors can adjust production proportions of uncooked pork and cooked pork in response to the regulations' effects. However, we find the simulation results are robust to a range of changes in elasticity of transformation. Hence, for simplicity, we assume the constant elasticity of transformation of 1.

The retail supply functions of uncooked and cooked pork products are found by adding processing and marketing costs to the farm-level supply functions:

$$Pr_F^S = a + c_F + b(Qr_F^S + Qr_N^S),$$

$$Pr_N^S = a + c_N + b(Qr_F^S + Qr_N^S).$$

We similarly derive farm-level demand for uncooked and cooked pork products from the retail demands by subtracting c_F and c_N from them:

$$Pr_F^D = (\gamma - c_F) - \beta_o Qr_F^D - \beta_c Qr_N^D,$$

$$Pr_N^D = (\theta - c_N) - \eta_o Qr_N^D - \eta_c Qr_F^D.$$

Equilibrium conditions without Proposition 12

Without Proposition 12, equilibrium conditions are the following:

$$Qf_F^{S*} = Qf_F^{D*} = Qf_F^*,$$

$$Qf_N^{S*} = Qf_N^{D*} = Qf_N^*,$$

$$Qr_F^{S*} = Qr_F^{D*} = Qr_F^*,$$

$$Qr_N^{S*} = Qr_N^{D*} = Qr_N^*,$$

$$Pf^{S*} = Pf^{D*} = Pf^*,$$

$$Pf_F^{S*} = Pf_F^{D*} = Pf_F^*,$$

$$Pf_N^{S*} = Pf_N^{D*} = Pf_N^*,$$

$$Pr_F^{S*} = Pr_F^{D*} = Pr_F^*,$$

$$Pr_N^{S*} = Pr_N^{D*} = Pr_N^*.$$

The equilibrium conditions consist of market clearing conditions in both the farm and retail markets. The asterisk denotes an equilibrium value. The sum of the equilibrium quantities of uncooked pork and cooked pork must equal the equilibrium quantity of finished hogs at retail weight equivalent:

$$Qf_F^* + Qf_N^* = Qf^*.$$

Final consumer demand for pork products under Proposition 12

Prop. 12 prevents non-compliant products from being sold in California. Hence, California becomes a market separate from the rest of North American for uncooked pork products. Hence, on the demand side, we must decompose the demand for uncooked pork into the California component and the rest of the North American (RNA) component. We assume that California has a demand share for uncooked pork equivalent to the California population share of the total North American market, which is 10.9% (denoted by the parameter, δ). That is, we have $Qr_F^D = \delta Qr_F^{D-CA} + (1-\delta)Qr_F^{D-RNA}$. Performing the basic algebra to get inverse demands yields:

$Pr_F^{D-CA} = \gamma - \frac{\beta_o}{\delta} Qr_F^{D-CA} - \beta_c Qr_N^D$, inverse demand for uncooked pork in CA,

$Pr_F^{D-RNA} = \gamma - \frac{\beta_o}{1-\delta} Qr_F^{D-RNA} - \beta_c Qr_N^D$, inverse demand for uncooked pork in RNA.

Cooked pork demand is unchanged by Prop. 12, and California continues to be integrated as part of the total market for cooked pork products: $Pr_N^D = \theta - \eta_o Qr_N^D - \eta_c Qr_F^D$.

Supply of market hogs with Proposition 12

Some fraction of North American hog production must convert to become Prop. 12 compliant to serve the California market. The fraction is determined in the market equilibrium and will be less than the California population share because uncooked pork will become more expensive in California, causing California sales to fall relative to the rest of the market. As noted, hog operations that convert to supplying Prop. 12 hogs will incur higher fixed and variable costs than non-converting operations (see Sections 4 and 5).

We model the choice of operation to become Prop. 12 compliant and undertake the production of Prop. 12 pork analogously to an entry choice. Existing farrowing operations have to choose whether to "enter" Prop. 12 production. Those operations that enter (that is, convert all or part of their operations) must forecast that the price premiums they receive for uncooked pork

will be sufficient to convert both fixed costs of entry and higher variable costs over a reasonable planning horizon. These operations will receive no price premiums for the cooked pork because non-compliant (and, thus, lower cost) operations also produce cooked pork.

As discussed in the preceding section (Section 3), conversion costs will be heterogeneous across hog operations, depending on the type of operation that a producer has in place. Operations with group housing or converting to group housing will have lower conversion costs than operations using individual-stall housing. Our research suggested that about 30% or 2.2 million gestating sows in North America are currently in group housing. We assumed that converting operations will come from this group and, thus, needed to consider costs of Prop. 12 compliance for these operations compared to their current group-housing costs. Converting operations will face one-time fixed costs to meet Prop. 12 standards, as well as higher ongoing operating costs compared to those that remain non-compliant for reasons discussed in the prior section.

Farrowing operations that can most efficiently (that is, at least cost) convert to Prop. 12 compliance will be the ones that will do so. In equilibrium, the "marginal" converting operation will anticipate enough incremental annual profits from the higher market value of Prop. 12-compliant hogs to just offset its higher variable operating costs of meeting Prop. 12 standards and also recover the annualized value of its fixed costs of conversion. All converting operations that are more efficient than the marginal converter will earn positive economic rents by converting their operations to Prop. 12 compliance.

The model assumes a uniform distribution of fixed per-hog conversion costs across group housing operations, with the parameters of the distribution set based on the results of our written surveys and interviews. We further assume that all converting operations will have the same

incremental variable costs to provide Prop. 12-compliant pork. The location in the uniform distribution of the marginal converter and, hence, the magnitude of conversion costs at the margin, the quantity of Prop. 12-compliant pork, and the price increase for uncooked pork needed to stimulate enough conversion of operations to be Prop. 12 compliant are determined jointly as part of the market equilibrium conditions. Define the term, ξ^*, the share of hog supply that converts in equilibrium to be compliant with Prop. 12 standards. Also, let us the parameter, ν, denote incremental variable costs per unit of hog production incurred by Prop. 12 converters. Then, the farm-level supplies of compliant and non-compliant live market hogs are as follows:

$Pf^{S-CA} = a + \nu + \frac{b}{\xi^*} \cdot Qf^{S-CA}$, the inverse farm-level supply of compliant live hogs,

$Pf^{S-RNA} = a + \frac{b}{1-\xi^*} \cdot Qf^{S-RNA}$, the inverse farm-level supply of non-compliant live hogs.

Pork processing and marketing sector under Proposition 12

The processing and marketing sector under Prop. 12 is handled analogously to the setting without Prop. 12. All market intermediaries operate with constant per-unit costs and act as perfect competitors. For reasons discussed earlier, processors and marketers will incur higher per-unit costs to bring Prop. 12-compliant, uncooked pork products from farm to retail or food service. We denote these unit costs as the parameter, $c_F^{CA} > c_F$ where the parameter, c_F, denotes the unit costs of marketing non-compliant uncooked pork from farm to retail or food service (for detailed information, see Section 5).

Then, the inverse supply of uncooked pork to the California market is as follows:

$$Pr_F^{S-CA} = (a + \nu + c_F^{CA}) + \frac{b}{\xi^*} \cdot Qf^{S-CA}.$$

Retail supplies of uncooked and cooked pork products to the rest of North America (RNA), the supply from non-compliant hogs are as follows:

$$Pr_F^{S-RNA} = Pf_F^{D-RNA} + c_F,$$

$$Pr_N^{S-RNA} = a + c_N + \frac{b}{(1-\xi)}(Qr_F^S + Qr_N^S).$$

Compliant hogs are also processed into cooked pork products. We assume that processors can produce cooked pork from compliant hogs at the same unit cost, c_N, as for producing it from non-compliant hogs. Hence, the inverse supply at retail of cooked pork is unaffected by Prop. 12:

$$Pr_N^S = Pf_N^D + c_N.$$

Derived (farm-level) demand for market hogs is found by subtracting off the relevant per-unit processing and marketing costs from the final demands:

$Pr_F^{D-CA} = (\gamma - c_F^{CA}) - \frac{\beta_o}{\delta} Qr_F^{D-CA} - \beta_c Qr_N^D$, inverse farm-level demand for F pork in CA,

$Pr_F^{D-RNA} = (\gamma - c_F) - \frac{\beta_o}{1-\delta} Qr_F^{D-RNA} - \beta_c Qr_N^D$, inverse primary demand for F pork in RNA,

$Pr_N^D = (\theta - c_N) - \eta_o Qr_N^D - \eta_c Qr_F^D$, inverse derived demand for N pork.

Equilibrium conditions with Proposition 12

In equilibrium, we must have those quantities demanded of compliant uncooked pork, non-compliant uncooked pork, and cooked pork products equal quantities of them produced:

$$Qf_F^{S-CA} = Qf_F^{D-CA} = Qf_F^{CA*},$$

$$Qf_F^{S-RNA} = Qf_F^{D-RNA} = Qf_F^{RNA*},$$

$$Qf_N^{S-CA} = Qf_N^{D-CA} = Qf_N^{CA*},$$

$$Qf_N^{S-RNA} = Qf_N^{D-RNA} = Qf_N^{RNA*}.$$

The fundamental conditions defining equilibrium for the Prop. 12 case are that the sum of the derived (farm-level) demands for the joint uncooked and cooked products yielded from a hog equal the farm supply of the live hog measured in retail weight for both CA-compliant and non-compliant hogs. Those conditions are as follows:

Live hog market:

$Pf^{S-CA*} = \frac{Qf_F^{S-CA*}}{Qf^{S-CA*}} \cdot Pf_F^{D-CA*} + \left(1 - \frac{Qf_F^{S-CA*}}{Qf^{S-CA*}}\right) \cdot Pf_N^{D*}$, equilibrium at the compliant hog market;

$Pf^{S-RNA*} = \frac{Qf_F^{S-RNA*}}{Qf^{S-RNA*}} \cdot Pf_F^{D-RNA*} + \left(1 - \frac{Qf_F^{S-RNA*}}{Qf^{S-RNA*}}\right) \cdot Pf_N^{D*}$, equilibrium at the non-compliant hog market.

Retail/food-service market:

$Pr_F^{S-CA} = Pr_F^{D-CA} = Pr_F^{CA*}$, equilibrium at the retail market for compliant uncooked pork;

$Pr_F^{S-RNA} = Pr_F^{D-RNA} = Pr_F^{RNA*}$, equilibrium at the retail market for non-compliant uncooked pork;

$Pr_N^S = Pr_N^D = Pr_N^*$, equilibrium at the retail market of cooked pork.

Each of these equilibrium expressions can be written in terms of the inverse demand and supply functions for the post-Prop. 12 market to specify the equilibrium conditions in terms of carcass-weight quantities of hogs/pork produced and solved for the equilibrium quantities:

Qf^{CA*}, annual quantity of Prop. 12-compliant market hogs;

Qf^{RNA*}, equilibrium quantity of non-compliant hogs;

Qf_F^{CA*}, equilibrium quantity of uncooked part of compliant slaughtered pork;

Qf_N^{CA*}, equilibrium quantity of cooked part of compliant slaughtered pork;

Qf_F^{RNA*}, equilibrium quantity of uncooked part of non-compliant slaughtered pork;

Qf_N^{RNA*}, equilibrium quantity of cooked part of non-compliant slaughtered pork.

These equilibrium outputs can, in turn, be substituted back into the inverse demand and supply specifications to determine equilibrium prices under Prop. 12:

Pf^{CA*}, compliant hog equilibrium price;

Pf^{RNA*}, non-compliant hog equilibrium price;

Pr_F^{CA*}, compliant uncooked pork price at retail market equilibrium;

Pr_F^{RNA*}, non-compliant uncooked pork price at retail market equilibrium;

Pr_N^*, cooked pork price at equilibrium.

Finally, ξ^*, the fraction of hog operations that convert to Prop. 12 compliance is determined in equilibrium such that the marginal converting operation earns a return from the price premium on compliant uncooked pork to just offset the annualized value of its upfront conversion costs and ongoing incremental operating costs.

7. Simulated Impacts of Proposition 12 on Pork Prices and Consumer and Producer Welfare

We categorize pork products into two types, such as uncooked pork and cooked pork. Prop. 12 regulates sales of uncooked pork but does not regulate sales of cooked pork. As discussed in Section 2 above, there is an ambiguity about whether ground pork is in uncooked pork or cooked pork. The CDFA proposed to exempt ground pork in sales regulations, but the proposed regulations are not yet finalized.

We consider two scenarios in simulations. First, ground pork is not regulated. Second, ground pork is regulated. Based on the 2018 US retail market sales data provided by the National Pork Board, about 58% of pork products are regulated by Prop. 12 when ground pork is not regulated. However, about 77% of pork products are regulated when ground pork is regulated.

Case 1. Simulation results when ground pork is not regulated

Our simulation model's first case describes when ground pork is not regulated by Prop. 12. The CDFA proposed the first case for the implementation of Prop. 12. The first case involves price elasticities of market demand for uncooked pork of -0.9 and cooked pork of -1.1, evaluated at the 2018 market equilibrium values (for more discussion on the choice of price elasticities, see Section 6).

Table 1 presents the simulation results. The simulation model projects that the farm price of Prop. 12-compliant pork will rise by 3.7% or about $2.90 per hundredweight in pork equivalent. The model projects almost no change in the price of non-compliant hogs or pork. The model further projects that the average price of uncooked pork in California will rise by 7.7% or about $0.25 per pound. The model projects almost no change in the retail price of cooked pork products.

The total quantity of live hogs is almost unchanged due to Prop. 12. However, the share of live hogs whose pork products are destined for California declines from 8.8% to 8.3% due to Prop. 12. California consumers will eat 6.3% less uncooked pork products because of Prop. 12. Quantity impacts for cooked pork products are negligible.

In total, California consumers will pay about 0.6% or $45 million annually more for pork consumption due to Prop. 12. Given 40 million California population, pork expenditure per capita will rise by about $1.12 per year. The expense change mostly comes from the expense change in uncooked pork. The expense change (about 0.9%) in uncooked pork is less than the retail price change (about 7.7%) in uncooked pork because Californians reduce uncooked pork consumption in response to the price change.

We used the change in consumer surplus to measure the change in consumer welfare of California consumers of pork products due to Prop. 12. The change in pork consumer surplus due to Prop. 12 incorporates two key factors: (a) that pork products subject to Prop. 12 regulations are more expensive and (b) that, due to the higher costs, California consumers will eat less of these products. We project that the consumer surplus will decline by about $317 million annually.

The simulation results above are the likely economic effects within California. However, differential regulation impacts across regulated regions and unregulated regions would also be important. Local and state governments' sales regulations within their jurisdiction can be interpreted as an inter-state trade barrier, which is potentially against the U.S. Commerce Clause (Sumner, 2017). Recently, California implemented shell egg sales regulations (Proposition 2 and Assembly Bill 1437) in 2015, and Carter, Schaefer, and Scheitrum (2020) provide evidence that California's regulations raised egg prices of both California and other regions in the United States.

However, our model projects little effects of California's pork sales regulations on the pork markets outside California. Our model projects almost no change in the retail price of non-compliant uncooked pork products and cooked pork products in the North American market. Quantity impacts for uncooked pork for the rest of North America and all cooked pork products are negligible. The impact of Prop. 12 on pork consumers in the rest of North America is negligible because Prop. 12 rules little impact prices and outputs. The current version of the paper does not provide a good explanation on the difference in impacts outside California between egg sales regulations and pork sales regulations. However, we expect that the impact

difference likely comes from the differences in the magnitudes of compliance costs and the coverage of regulated products.

Table 1. Impacts of Proposition 12 on Hog and Pork Prices and Outputs When Ground Pork Is Not Regulated

	Variable	Unit	Base	Prop. 12	$ Change	% Change
	Prices					
Pf	Ave. price all slaughter hogs	$/cwt.	79.2	79.3	0.10	0.2
Pf^{CA}	CA Compliant hogs	$/cwt.	79.2	82.1	2.90	3.7
Pf^{RNA}	Non-compliant hogs	$/cwt.	79.2	79.0	-0.20	-0.2
Pr_F	Ave. retail price uncooked pork	$/lb.	3.30	3.32	0.02	0.7
Pr_F^{CA}	CA Compliant pork	$/lb.	3.30	3.55	0.25	7.7
Pr_F^{RNA}	Non-compliant pork	$/lb.	3.30	3.29	-0.1	-0.2
Pr_N	Retail price cooked pork	$/lb.	3.79	3.79	0.004	0.1
	Hog and Pork Quantity				Units Change	% Change
Qf	Number of hogs slaughtered	millions	145.0	144.5	-0.5	-0.3
	Pork quantity (includes exports)	mil. cwt.	233.1	232.4	-0.7	-0.3
	Uncooked quantity of pork	mil. cwt.	147.0	146.2	-0.8	-0.6
	Cooked quantity of pork	mil. cwt.	86.1	86.2	0.1	0.1
	Share California in uncooked pork	%	8.84	8.34	-0.50	-5.7
	Retail Pork in North America					
Qr_F	Quantity of retail uncooked pork	mil. cwt.	119.5	118.8	-0.7	-0.6
Qr_F^{CA}	Compliant (California)	mil. cwt.	13.0	12.2	-0.8	-6.3
Qr_F^{RNA}	Non-compliant (non-California)	mil. cwt.	106.5	106.6	0.1	0.1
Qr_N	Quantity of retail cooked pork	mil. cwt.	85.5	85.6	0.1	0.1

Case 2. Simulation results when ground pork is regulated

As noted, the second case describes when ground pork is subject to Prop. 12. Under the second case, about 77% of total retail pork becomes regulated by Prop. 12, which is bigger than the value of 58% under the first case. We also explore more variation in the price elasticities of demand for uncooked and cooked pork, 0.8 and 1.3, respectively. Consumers will have fewer opportunities to replace uncooked pork in response to changes in uncooked pork prices because they lose opportunities to substitute ground pork for some uncooked pork products. However, consumers will become more elastic to changes in cooked pork prices because they gain

opportunities to substitute ground pork for some cooked pork products, under the second case, compared to the first case.

Compared to the first case, a major consideration in this second simulation is that the more products are subject to Prop. 12, the less the price increases for regulated products because the compliant costs can be spread across more products. Thus, we see in Table 2 that the price increase for uncooked pork is only 6.2%, while the quantity decrease is only 4.6%, due both to a smaller percent price increase and a smaller price elasticity of demand for uncooked pork than in the base case.

In total, California consumers will pay about 1.0% or $79 million annually more for pork consumption due to Prop. 12. Pork expenditure per capita will rise by about $2.00 annually. The loss in consumer benefit, measured by consumer surplus, for this case, is $347 million annually. Both the expenditure increase and the benefit loss are greater than in the base case. Even though the price increase (in percentage) for uncooked pork is less in the second case, much more retail pork is subject to the second case's regulations compared to the base case.

Table 2. Impacts of Proposition 12 on Hog and Pork Prices and Outputs When Ground Pork Is Regulated

	Variable	Unit	Base	Prop. 12	$ Change	% Change
	Prices					
Pf	Ave. price all slaughter hogs	$/cwt.	79.2	79.3	0.10	0.2
Pf^{CA}	CA Compliant hogs	$/cwt.	79.2	82.1	2.90	3.7
Pf^{RNA}	Non-compliant hogs	$/cwt.	79.2	79.0	-0.20	-0.2
Pr_F	Ave. retail price uncooked pork	$/lb.	3.35	3.37	0.02	0.6
Pr_F^{CA}	CA Compliant pork	$/lb.	3.35	3.56	0.21	6.2
Pr_F^{RNA}	Non-compliant pork	$/lb.	3.35	3.35	-0.004	-0.1
Pr_N	Retail price cooked pork	$/lb.	4.00	4.00	0.004	0.1
	Hog and Pork Quantity				Units Change	% Change
Qf	Number of hogs slaughtered	millions	145.0	144.5	-0.5	-0.4
	Pork quantity (includes exports)	mil. cwt.	233.1	232.4	-0.7	-0.4

	Uncooked quantity of pork	mil. cwt.	185.8	185.0	-0.8	-0.4
	Cooked quantity of pork	mil. cwt.	47.3	47.4	0.1	0.1
	Share California in uncooked pork	%	9.31	8.92	-0.39	-4.2
	Retail Pork in North America					
Qr_F	Quantity of retail uncooked pork	mil. cwt.	158.4	157.8	-0.6	-0.4
Qr_F^{CA}	Compliant (California)	mil. cwt.	17.3	16.5	-0.8	-4.6
Qr_F^{RNA}	Non-compliant (non-California)	mil. cwt.	141.2	141.3	0.1	0.1
Qr_N	Quantity of retail cooked pork	mil. cwt.	46.5	46.6	0.1	0.1

Comparison with Sumner et al. (2020)

The CDFA is in charge of specifying the regulations according to Prop. 12 and proposed those regulations in early 2020. The CDFA reported Standardized Regulatory Impact Assessment (SRIA) of Proposed Regulations to Implement Proposition 12 (Sumner et al., 2020). SRIA summarizes the proposed regulations and reports simulation results about the proposed regulations' likely economic effects. We compare the SRIA simulation results with our simulation results in this subsection.

Before comparing the simulation results, let us compare the simulation models. First, this paper specifies the supply and demand functions linearly. However, SRIA specifies those supply and demand functions as a log-differential form. Hence, this paper's model characterizes the market outcomes with and without the regulations, while SRIA's model characterizes percentage changes in market outcomes by the regulations. Second, the two models use the same price elasticities of supply and demand. Although SRIA reports more scenarios with different price elasticities, the two models use the same price elasticities for model calibration in a long-run situation. We use the long-run situation for comparison. Third, the two models differ in the coverage of the geographic area. This paper specifies the retail market outside California in addition to the California one, while SRIA specifies only the California retail market. Fourth, our

model considers heterogeneity in compliant costs at farms, while the SRIA model assumes homogeneity in compliant costs at farms.

The SRIA simulation results are similar to our simulation results. When ground pork is not regulated, the California retail price of uncooked pork will rise by about 7.5% under the SRIA model and 7.7% under our simulation model. California's uncooked pork consumption will also fall by about 5.6% under the SRIA model and 6.3% under our simulation model.

For sensitivity analysis, additionally, we did simulations with different elasticity values. The simulation results are robust to different elasticity values, although this version of the paper does not report the results. For a general discussion on sensitivity analysis, we also plan to consider assuming a distribution on the main parameters to draw a distribution of simulation results (Lee, Sumner, and Champetier, 2018).

8. Conclusions

There have been many government mandates, labeling rules, and food supplier adjustments that address various social and environmental claims about food production in recent years. Those regulations limit both farming practices and sales of related consumer products within a jurisdiction. Regulating product sales based on farming practices is complicated. Farms typically supply raw materials for processors or distributors. Processors and distributers produce and supply consumer products, and wholesalers supply them to retailers and foodservice providers. The variety of food products has widened as the food supply chain has developed to satisfy the demand of consumers who value many attributes in food consumption. It adds complexity to implement regulations as the number of consumer products increases. Regulators choose a range

of regulated consumer products, considering costs of implementation actions such as certification, record keeping, and monitoring.

This paper develops the economics of these issues using the case of regulations on pork sold in California. We constructed an economic model of the North American pork industry. The model covers both the United States and Canada in the geographical area and describes hog production, processing, marketing, retailing, and foodservice in the pork supply chain. Given the best available estimates of cost compliance at each stage, the model simulates changes in pork prices, production and consumption of pork products, and consumer welfare due to Prop. 12.

Simulation results show that: (1) compliant farrowing operations incur higher costs; (2) compliant processing and distribution operations incur higher costs; (3) covered pork products have higher retail prices reflecting these costs; (4) with higher prices, California consumers of covered pork products have substantial welfare losses; (5) impacts on non-covered prices and quantities are very small; and (6) impacts on consumers outside California are very small.

Our simulation frameworks should apply broadly to other regulations. Those regulations require restrictive production practices at farms that raise production, processing, and marketing costs. Those regulations also have limited coverage of regulated consumer products in sales. For example, restrictive farm animal treatment, limited use of antibiotics, and methane emission management have been commonly discussed in livestock production. Like hogs, other big farm animals raised for meat, such as cattle, hogs, and meat chickens, are used for various meat products and ingredients for various meals at foodservice providers. Hence, regulators will face similar issues that we discussed above in the context of California's regulations, and our framework would be useful. We also expect our framework to be applicable for analyzing genetically modified food regulations. Consumers' perceptions and demand for regulations on

genetically modified crops, including soybeans, differ in the final uses such as meals for human beings and fuels for cars. In addition to the examples we mentioned above, our framework would be applicable for other policy cases when there are differential regulation costs due to limited coverage of regulated products.

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