The Economics of Regulations Limiting Farming Practices for Products Sold within Jurisdiction:

California's 2022 Pork Rules

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Subnational jurisdictions, e.g., U.S. states and municipalities, are increasingly imposing regulations on farm production practices (Sumner 2017). Examples include restrictions on farm organizational structure, regulation of farming practices that cause pollution, setting of minimum wages and working conditions for farm labor, and limiting the use of inputs such as chemicals and fertilizers in crop production and hormones and antibiotics in livestock production (Alwang, Wooddall-Gainey, and Johnson 1991; Sunding 1996; Metcalfe 2000; Hayes and Jensen 2003; Schroeter, Azzam, and Aiken 2006; Zhang 2018). Although such regulations impact cost of production and competitiveness of farms located within those jurisdictions, the products produced under these various regulatory regimes are eventually commingled in the supply chain without identity preservation and sold to consumers in integrated markets.

Such regulations differ importantly in their economic impact from an emerging body of laws that control production practices for farm products that are sold within the regulating jurisdiction regardless of where the products were produced. A key example is California Proposition 12 (Prop 12) approved overwhelmingly by voters in November 2018 and set to be implemented fully in January 2022. Prop 12 sets specific housing requirements for egg-laying hens, breeding pigs, and calves raised for veal, and prohibits the sale in California of products derived from covered animals maintained in housing that does not meet these standards, regardless of where the covered animals were located. Other examples include California's AB 1437 which specifies minimum space requirements for egg-laying hens (Matthews and Sumner 2015), the Massachusetts Minimum Size Requirements for Farm Animal Confinement proposition (aka Question 3) passed in November 2016, the Arizona Farm Animal Confinement Initiative proposed for the ballot in 2022, state and local bans on the sale of foie gras, and bans on the sale of canned tuna caught with drift nets (Ramach 1996).[1, 2]

Regulations of this type have been slow to emerge, at least in part due to belief that they would be enjoined by the courts as a violation of the Commerce Clause (Article 1, Section 8, Clause 3) of the U.S. Constitution (Sumner 2017). In the example of pork regulations in Prop 12, in July 2021, the U.S. Court of Appeals for the 9th Circuit affirmed the judgement of the U.S. District Court for the Southern District of California upholding Prop 12.[3] However, in September 2021, the National Pork Producers Council appealed to the U.S. Supreme Court, and the supreme court agreed to hear the case.[4]

Given the emerging importance of regulations of this type, the courts' support of them, and the controversy surrounding them, it is important to understand their unique economic impacts. In this paper we utilize Prop 12's regulations on breeding pigs to study the economic impacts of these regulations. We develop a conceptual model of a vertical food market involving farms, intermediaries, and consumers. Although the model is developed in the context of the North American hog/pork market, the key economic principles apply generally to subnational regulation of production practices for food products sold within the jurisdiction. We then parameterize the model based on information gathered from a survey of growers and processors

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[1] The passage of such laws and the courts' support of them to date have led to, thus far, unsuccessful attempts at the federal level to prohibit states from enacting this type of legislation. One key example was the Protect Interstate Commerce Act proposed as part of the 2018 U.S. Farm Bill, but eventually excluded from the final bill (Vogeler 2020).

[2] Related examples also emerge in international trade when importing countries impose restrictions on agricultural products allowed to enter the country.

[3] In an opinion filed July 28, 2021 a panel of the Ninth U.S. Circuit Court of Appeals upheld Prop 12, ruling it did not violate the Commerce Clause (https://www.courthousenews.com/wp-content/uploads/2021/07/Pork_producers_California-9CA.pdf).

[4] The petition was filed on September 27, 2021 and was granted on March 28, 2022. More information is available at https://www.supremecourt.gov/docket/docketfiles/html/public/21-468.html.

in the pork industry and from the scientific literature to estimate the impacts of Prop 12 on prices, outputs, and economic welfare.

Regulations such as Prop 12 also differ in their economic impacts from private standards imposed on farm production practices by downstream buyers such as grocery retailers and food-service operators. Such standards were studied by Saitone, Sexton, and Sumner (2015) and applied to restrictions on antibiotic use in pork production. The essential economics of private standards include the decision of downstream buyers whether to impose such standards and the decision of consumers whether to patronize sellers who adopt such standards or to avoid higher product costs by shopping elsewhere. These elements of seller and consumer choice are not present when the regulation applies to all products sold in the jurisdiction.

Although we use Prop 12 as an example of subnational regulations on food products based on production practices, Prop 12 and, more broadly, regulations on farm animal treatment themselves have received attention in the literature. Our study extends the understanding of the impacts of those farm animal treatment regulations. Many states, including Arizona, California, and Massachusetts, have passed laws on restrictive animal housing standards on products sold within their jurisdictions. Most previous studies have paid attention to the case of California for analysis (Mullally and Lusk 2017; Carter, Schaefer, and Scheitrum 2020; Oh and Vukina 2022). Mullally and Lusk (2017) analyzed the impact of Assembly Bill 1437 that, from 2015, banned egg products from egg layers confined in less than 116 square inches per hen and found evidence that AB 1437 raised the retail egg prices and reduced egg consumers' welfare. Carter, Schaefer, and Scheitrum (2020) also studied the same law and found the law's impact persisted relatively in a long run (2015-2017) and modestly spread outside the regulating jurisdiction. California strengthened the farm animal treatment regulations through Prop 12 in 2018, which requires cage-free housing for selling egg products in California. Oh and Vukina (2022) simulated the impact of Prop 12 on the California shell egg market (about $72 million consumer surplus loss). Our study is comparable to the previous studies in that we analyze the impact of Prop 12, and our model incorporates both the regulating jurisdiction and the regions outside of it.

However, our study differs from the previous studies in several important aspects. First, we study the impacts on the pig and pork markets rather than the chicken and shell egg markets. Although most farm animal treatment laws cover breeding pigs' housing, the impacts on the pig and pork markets have received little attention despite the importance of the hog and pork industry in agricultural production and food consumption. Second, our analysis considers the case when a mandate only applies to a portion of the output of the live animal. Farm animals usually produce many products, and the existing laws restrict selling a subset of those products. In our example, Prop 12 does not restrict selling cooked pork products (e.g., cooked sausages, hotdogs, and canned pork). We study the implications of such incomplete product coverage, which has received little attention in the literature. Third, our model allows a conversion of capital and heterogeneity in farm compliance costs to consider farms' long-run response explicitly. Fourth, we consider segregation costs along food supply chains. The existing laws require keeping the identity of compliance preserved along the supply chain, and segregation is usually required for traceability. General implications of traceability and segregation along food supply chains have been studied in the literature (Pouliot and Sumner 2008; Pendell et al. 2010), but their roles have received little attention in farm animal treatment regulations. We expect that the implications of our study's distinctive features above would not be limited within the literature of farm animal treatment regulations and would help us obtain a comprehensive understanding of regulations of production practices and product attributes conducted by governments and private sectors.

In what follows, we first present an overview of how subnational regulations of production practices for products sold in their jurisdictions impact costs along the supply chain, and then utilize this knowledge to set forth an economic model to study such regulations formally. We then parameterize the model to fit Prop 12 and simulate its impacts on prices, outputs, and economic welfare. Results show that; (i) compliant farrowing operations will incur about 4% higher costs; (ii) retail prices of covered cuts of pork will rise by about 7%; (iii) California consumers will incur annual welfare losses of about $300 million; (iv) compliant hog producers will actually on average receive modestly greater profits, and (v) impacts on prices and quantities of products sold outside of California and of non-covered pork products are minimal.

Supply Chain Impacts of Subnational Regulations on Food Production

The impacts of Prop 12 and related subnational regulations depend importantly on the cost increases they impose at different stages of the supply chain. In general and for Prop 12 specifically, both fixed and variable farm production costs will increase. Most of the subnational regulations to date apply to animal housing, so compliant firms will incur fixed costs of adapting housing to a regulation's requirements, as well as additional variable costs associated with deviating from conventional practices. Farms considering conversion must, thus, determine whether a discounted incremental revenue stream from serving the regulating jurisdiction will be sufficient to cover the upfront and recurrent costs of the regulation.

An important but little studied aspect of these conversion costs is that they are likely to be heterogeneous across farms. In our application to Prop 12 and hog farrowing operations, we estimate that 30% of such operations operate presently with group housing, although with per sow space that is insufficient to meet Prop 12's standards. These farms will be able to convert to Prop 12 compliance at lower costs than operations using stall housing. Thus, the marginal converting operation will just break even (on expectation) from doing so, while inframarginal converters will earn incremental profits from converting.

Elements of cost that are unique to subnational or private regulations on sale of products are those for segregation of regulated product in the supply chain. Keeping the identity of compliance requires processors to segregate both compliant and noncompliant farm product and compliant and noncompliant finished products, including creating new stock keeping units (SKUs) (Informa Economics 2010; Sumner and Zuijdwijk 2019).

Unlike regulations that concern only production practices within the regulating jurisdiction and, thus, impact live-animal production, regulations that restrict finished products that can be sold within the jurisdiction must specify the product coverage of the regulations. Most farm products serve as inputs into multiple finished products. For example, the livestock products at issue with most animal housing regulations may be sold to consumers in either cooked or uncooked formats and may be mixed with other products in sausages, soups, prepackaged dinners, etc. Higher costs associated with complying with the regulation can be recovered only on the subset of products covered under the regulation. Products coming from compliant farm product but not covered under the law can receive no price premium because they compete with products from noncompliant farm product.

Coverage of finished products is a challenge for subnational regulating authorities because the wider the set of final products included under the regulation the greater will be the challenge to compliance and enforcement and the more economic actors that will be involved. Prop 12 applies only to uncooked pure pork products sold in California, about 60% of the meat from a hog. The fact that only a subset of finished products that use the farm product input will be subject to the regulation creates an opportunity for consumers to avoid regulation-induced price increases by substituting non-covered products in place of those subject to the regulation.

Economic Model

We begin by modeling a perfectly competitive North American pork supply chain in the absence of regulation to establish a baseline model.[5] We then extend the model to incorporate the impacts of Prop 12. We categorize supply-chain participants into three groups: (i) farms that produce a raw-product input, (ii) intermediaries that convert the farm product into finished products and supply those products to consumers, and (iii) consumers who buy those products at retail through grocery stores or food-service establishments. For simplicity, we classify products into two composite categories: covered products and non-covered products.

Primary supply of farm product: To maintain tractability with a relatively small number of parameters, we use a linear market supply function for the farm product:

$$P_f^S = a + bQ_f^S, \tag{1}$$

[5] Imperfect competition may occur in food supply chains (Sexton 2000, 2013). However, empirical estimates of processor market power in red-meat industries have generally revealed at most only mild distortions from competitive behavior (Wohlgenant 2013, Sexton and Xia 2018), making perfect competition a reasonable simplifying assumption. The model could be extended to allow intermediary oligopoly and/or oligopsony power at the complexity cost of introducing multiple market-power parameters.

where a subscript f represents farms, P denotes price, and Q is quantity, a superscript S denotes a supply relationship, so Q_f^S denotes the quantity of farm raw material supplied.[6]

Primary demand for final products: We also specify the inverse final demand for covered and non-covered products in a linear form:

$$P_{r,C}^D = \gamma - \beta_{cc} Q_{r,C}^D - \beta_{cn} Q_{r,N}^D, \tag{2}$$

$$P_{r,N}^D = \theta - \eta_{nn} Q_{r,N}^D - \eta_{nc} Q_{r,C}^D, \tag{3}$$

where subscript r represents final demand (retail plus food service), subscripts C and N denote covered and non-covered products respectively, and superscript D denotes a demand relationship. P_r is the final product price, and Q_r is the quantity sold at retail and food service. Substitution by consumers between covered and non-covered products can occur based upon the cross-price coefficients, β_{cn} and η_{nc}.

Processing and marketing sector: We assume homogeneous intermediaries who acquire the farm product and convert it into final products sold downstream to consumers either at retail or food-service establishments. A representative processor can produce two retail products using two inputs, the finished hogs, q_f, and the composite of other inputs, K, where lower case q denotes firm-level values. No substitution is allowed between hogs and other inputs in production of cuts of pork and other pork products.[7] The finished hogs are transformed into the two outputs under variable proportions because specific parts of a hog carcass are more suitable for one type of pork than the other. For example, bacon and pork chops cannot be made from

[6] Although the conceptual model could be specified with more general functional forms, specific functions are needed to implement the simulation model that is essential to this research, so we develop the model directly in a format conducive to conducting simulations.

[7] Some prior studies (Wohlgenant 1989, 1993; Pendell et al. 2010) consider potential substitution between farm products and other inputs in production. However, because of the limited substitution of other inputs such as labor for hog carcass to produce pork products, we simplify the model by assuming no substitution. Rickard and Sumner (2008) allow substitution of other inputs for tomatoes in making tomato products with relatively small impacts on results.

parts that would otherwise make sausage. The transformation is represented by a constant elasticity of transformation (CET) production possibility frontier (Powell and Gruen 1968):

$$q_f = A\left(\alpha\left(q_{r,C}\right)^{\rho} + (1-\alpha)\left(q_{r,N}\right)^{\rho}\right)^{\frac{1}{\rho}}, \quad (4)$$

where $A > 0$ is a scale parameter, $0 < \alpha < 1$ is a share parameter, and $1 < \rho < \infty$ is a parameter that determines the elasticity of transformation τ. Specifically, $\tau = 1/(\rho - 1)$. For example, the CET production possibility frontier approaches fixed proportions as $\rho \to \infty$ (which implies $\tau \to 0$) and approaches perfect transformation ($\tau \to \infty$) as $\rho \to 1$.[8]

An illustration of this production technology is provided in figure 1 using three production possibility frontiers. Three frontiers use three different values of the elasticity of transformation, 0.2, 0.5, and 1.0, but pass the same baseline quantity point of the North American pork industry. Each point on each frontier represents the combination of the maximum quantities of covered pork and non-covered pork that can be produced for a given quantity of finished hogs. The area on and within each frontier is the corresponding production possibility set. The tradeoff between covered and non-covered products increases as the elasticity of transformation increases.

[8] See Appendix A for the derivation of these two special cases.

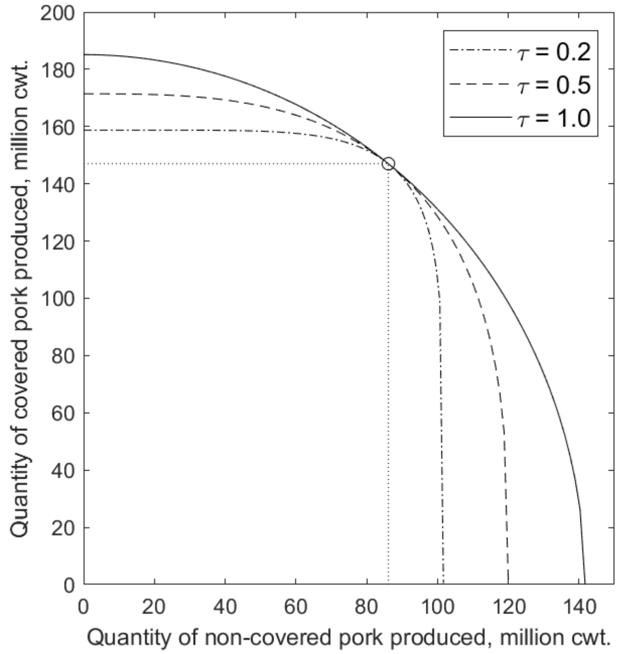

Figure 1. Three Production Possibility Frontiers Passing the Baseline Quantity Point
Notes. cwt=hundredweight. These production possibility frontier curves are for the intermediaries using the farm product to produce the two products: covered product and non-covered product. The term τ represents the elasticity of transformation. The circle point indicates the 2018 quantities of the two products in the North American pork market, which represents the baseline of policy simulations below.

For simplicity, costs associated with the use of other inputs, K, in processing and marketing can be written as a linear form, $c_C q_{r,C} + c_N q_{r,N}$, where the term c_C is the constant per-unit processing cost for covered pork and c_N is that for non-covered pork.[9]

We assume constant returns to scale for production and marketing of both types of pork products.[10] With constant returns to scale and constant prices, the choice of the total output and amount of hogs processed and marketed by a firm is not determinant unless additional constraints are imposed on the problem, such as a binding plant-capacity constraint. We consider the realistic setting whereby the representative processor has secured a contract commitment to

[9] A linear specification for non-farm inputs in food processing is a common simplification (Wohlgenant 1989; Tomek and Kaiser 2014, p.108; Saitone, Sexton, and Sumner 2015).
[10] See the appendix where we show how constant returns enter the technology that allows substitution across outputs.

procure q_f hogs, an amount we assume represents the efficient processing capacity. The processor's short-run decision then is the choice of outputs to produce, given the live animal input:

$$\max_{q_{r,C},q_{r,N}} (P_{r,C} - c_C)q_{r,C} + (P_{r,N} - c_N)q_{r,N} \text{ subject to } q_f = A\left(\alpha(q_{r,C})^{\rho} + (1-\alpha)(q_{r,N})^{\rho}\right)^{\frac{1}{\rho}}. \quad (5)$$

Solving the first-order conditions and aggregating across intermediaries,[11] we obtain the supply functions of the two retail products conditional on the live hog quantity (see the end of this note for derivation):

$$Q_{r,C}^{S} = \frac{Q_f^S}{A}\left(\alpha + (1-\alpha)\left(\frac{\alpha}{1-\alpha}\frac{P_{r,N}^S - c_N}{P_{r,C}^S - c_C}\right)^{\tau+1}\right)^{-\frac{\tau}{\tau+1}}, \quad (6)$$

$$Q_{r,N}^{S} = \frac{Q_f^S}{A}\left((1-\alpha) + \alpha\left(\frac{1-\alpha}{\alpha}\frac{P_{r,C}^S - c_C}{P_{r,N}^S - c_N}\right)^{\tau+1}\right)^{-\frac{\tau}{\tau+1}}. \quad (7)$$

The superscript S denotes a supply relation. For both supply functions, as expected, the quantity supplied rises as the own price rises, while it falls as the cross price rises because $\tau > 0$ and $0 < \alpha < 1$. After steps of algebra, the supply functions can be written as follows (see Appendix. A for derivation):

$$Q_{r,C}^{S} = Q_f^S\left(\frac{1}{A}\right)^{1+\tau}\left(\frac{P_{r,C}^S - c_C}{\alpha P_f^S}\right)^{\tau}. \quad (8)$$

$$Q_{r,N}^{S} = Q_f^S\left(\frac{1}{A}\right)^{1+\tau}\left(\frac{P_{r,N}^S - c_N}{(1-\alpha) P_f^S}\right)^{\tau}. \quad (9)$$

[11] The second order condition is strictly satisfied under $1 < \rho < \infty$ or $0 < \tau < \infty$ where τ is the elasticity of transformation, which guarantees a unique interior solution. In the fixed proportions case where $\tau = 0$, this economic solution is trivial at the fixed ratio.

Equations (8) and (9) are helpful to understand the effect of incremental farm costs of hogs caused by the regulations, which will be introduced below. Using the CET relation (equation 4), we can obtain the derived demand for live hogs as follows:

$$Q_f^D = A\left(\alpha\left(Q_{r,C}^D\right)^\rho + (1-\alpha)\left(Q_{r,N}^D\right)^\rho\right)^{\frac{1}{\rho}}. \tag{10}$$

Equilibrium Conditions without Regulations

The following sets of conditions characterize the equilibrium prices and quantities in the baseline case:

$$Q_f^* = Q_f^{D*} = Q_f^{S*}; P_f^* = P_f^{D*} = P_f^{S*}, \tag{11}$$

$$Q_{r,C}^* = Q_{r,C}^{D*} = Q_{r,C}^{S*}; P_{r,C}^* = P_{r,C}^{D*} = P_{r,C}^{S*}, \tag{12}$$

$$Q_{r,N}^* = Q_{r,N}^{D*} = Q_{r,N}^{S*}; P_{r,N}^* = P_{r,N}^{D*} = P_{r,N}^{S*}, \tag{13}$$

$$\frac{Q_{r,C}^*\left(P_{r,C}^* - c_C\right) + Q_{r,N}^*\left(P_{r,N}^* - c_N\right)}{Q_f^*} = P_f^*. \tag{14}$$

The asterisks denote equilibrium values. The first three sets of conditions, (11), (12), and (13), are market-clearing conditions. The last set of conditions, (14), describes the fundamental condition defining competitive equilibrium. The weighted average of two products' values after excluding the marketing margin equals the price of live hogs.

Market in the Presence of Subnational Regulations

Now consider regulations imposed on products in a subnational jurisdiction, which takes only a portion of the total market demand. The regulated jurisdiction becomes a market separate from the other jurisdictions for covered products because covered products cannot be sold within its jurisdiction unless they satisfy the regulations.[12]

Primary demand for products with regulations: Assume that the regulated jurisdiction has a demand share, denoted by δ, for the total covered products:

$$Q_{r,C}^{D} = \delta Q_{r,C}^{D,R} + (1-\delta) Q_{r,C}^{D,U}, \tag{15}$$

where superscripts R and U denote the regulated market unregulated market, respectively. Combining (2) and (15), we obtain the inverse demand functions:

$$P_{r,C}^{D,R} = \gamma - \frac{\beta_{cc}}{\delta} Q_{r,C}^{D,R} - \beta_{cn} Q_{r,N}^{D}, \tag{16}$$

$$P_{r,C}^{D,U} = \gamma - \frac{\beta_{cc}}{1-\delta} Q_{r,C}^{D,U} - \beta_{cn} Q_{r,N}^{D}. \tag{17}$$

Non-covered product demand is integrated and unchanged by the regulation and is specified in (3).

Supply of farm product with regulations: Each farm *i* chooses whether to produce farm product eligible for use as input into products destined for the regulated jurisdiction. As noted, serving the regulated jurisdiction involves incurring a fixed conversion cost to reconfiguring operations to meet the regulations and a higher variable cost associated with less efficiency in production because of restricted practices.

Conversion costs differ across farms, for example, because of a difference in facilities and equipment before the regulations. Some farms will have relatively low conversion costs

[12] Consumers near the border of a regulated jurisdiction may shop in a nearby unregulated jurisdiction to avoid higher prices caused by regulation. Studies have provided evidence on cross-border shopping for products such as alcohol (Asplund, Friberg, and Wilander 2007) and lotteries (Knight and Schiff 2012). To our knowledge the only study of cross-border shopping for food is Tosun and Skidmore (2007) who reported a small decrease in the revenue from food products when West Virginia changed the sales tax on food products. We expect that the cross-border shopping due to Prop 12 will be minimal for most California consumers because the regulated pork products affect only a small portion of food budgets and opportunities to shop across the state's border are limited, given concentrations of population along the Pacific Coast.

because their extant operations come closer to compliance with the requirements of the regulations than other farms' operations. The average conversion cost, denoted by σ_i, is the sum of an annualized value of incremental fixed cost per farm product, denoted by ϕ_i, and an annual incremental unit variable cost, assumed to be constant across farms and denoted by ν:

$$\sigma_i = \phi_i + \nu, \tag{18}$$

Without loss of generality, we order farms along a continuum from the lowest average conversion cost, $\underline{\sigma}$, to the highest, $\overline{\sigma}$. For simplicity, we assume that the average conversion cost is uniformly distributed. That is, each farm has a cost, $\sigma_i \sim U[\underline{\sigma}, \overline{\sigma}]$, that characterizes its total annualized incremental cost on a per-unit quantity of the raw product of becoming compliant. Each farm adopts the restricted practices if

$$P_f^{S,R} - P_f^{S,U} \geq \sigma_i, \tag{19}$$

and maintains the lower-cost standard practices otherwise. Only farms with low compliance costs will adopt the restricted practices, while those with higher costs continue to use the standard practices. The marginal farm that is indifferent between compliance and non-compliance has incremental cost $\tilde{\sigma}$ such that

$$P_f^{S,R} - P_f^{S,U} = \tilde{\sigma}. \tag{20}$$

Equation (20) has important implications. First, the larger the share of the regulated jurisdiction, the larger is a critical value, $\tilde{\sigma}$, and therefore the larger the implied price differential must be to elicit sufficient conversion. Second, restrictions raise profits for inframarginal adopters. Third, restrictions have effects on the unregulated share of the market through the re-allocation of farm production between the regulated and unregulated sectors.

The supply function for farms that do not comply with the regulation is unaffected and given by (1). Because of the incremental variable cost, ν, the supply function of individual farms for the regulated jurisdiction is

$$P_f^{S,R} = a + \nu + bq_{f,i}^{S,R}, \tag{21}$$

where the variable $q_{f,i}^{S}$ is the quantity of hogs supplied by i farm.

The market supply function of farm product from each type of farm is the integration of quantities over farms in each group at each price differential:

$$Q_f^{S,U} = \int_{\tilde{\sigma}}^{\overline{\sigma}} q_{f,i}^{S,U}\, dF(\sigma_i) = \int_{\tilde{\sigma}}^{\overline{\sigma}} \left(\frac{P_f^{S,U} - a}{b}\right) dF(\sigma_i) = \left(\frac{P_f^{S,U} - a}{b}\right) \cdot \left(1 - \tilde{\xi}\right), \tag{22}$$

$$Q_f^{S,R} = \int_{\underline{\sigma}}^{\tilde{\sigma}} q_{f,i}^{S,R}\, dF(\sigma_i) = \int_{\underline{\sigma}}^{\tilde{\sigma}} \left(\frac{P_f^{S,R} - a - \nu}{b}\right) dF(\sigma_i) = \left(\frac{P_f^{S,R} - a - \nu}{b}\right) \cdot \tilde{\xi}. \tag{23}$$

where $\tilde{\xi} = \left(\tilde{\sigma} - \underline{\sigma}\right)/\left(\overline{\sigma} - \underline{\sigma}\right)$ represents the fraction of farms that convert to utilizing the restricted practices. The inverse aggregate supply functions are

$$P_f^{S,U} = a + \frac{b}{1 - \tilde{\xi}} Q_f^{S,U}, \tag{24}$$

$$P_f^{S,R} = a + \nu + \frac{b}{\tilde{\xi}} Q_f^{S,R}. \tag{25}$$

<u>Processing and marketing sector with regulations</u>: The model specifies an incremental cost at primary processors as a constant amount per hog, Δc, due to segregations, certification, and recordkeeping. Note that non-covered pork from compliant hogs is not differentiated from non-covered pork from non-compliant hogs. Hence, Δc will be transferred solely through a shift

of the supply function of covered pork from compliant hogs, $Q_{r,C}^{R}$.[13] Other costs, Δc_C, can be incurred for handling compliant pork throughout the downstream marketing chain:

$$Q_{r,C}^{S,R} = Q_f^{S,R}\left(\frac{1}{A}\right)^{1+\tau}\left(\frac{P_{r,C}^{S,R} - c_C - \left(\frac{\Delta c}{\mu^*} + \Delta c_C\right)}{\alpha P_f^{S,R}}\right)^{\tau} \text{ where } \mu^* = \frac{Q_{r,C}^*}{Q_{r,C}^* + Q_{r,N}^*}. \tag{26}$$

The asterisk denotes equilibrium values. The term $\Delta c_C/\mu^*$ is the incremental processing and marketing cost transferred to the covered pork based on its per unit quantity. The other supply functions can be modeled analogously to those without regulations:

$$Q_{r,C}^{S,U} = Q_f^{S,U}\left(\frac{1}{A}\right)^{1+\tau}\left(\frac{P_{r,C}^{S,U} - c_C}{\alpha P_f^U}\right)^{\tau}, \tag{27}$$

$$Q_{r,N}^{S} = Q_{r,N}^{S,R} + Q_{r,N}^{S,U} = Q_f^{S,R}\left(\frac{1}{A}\right)^{1+\tau}\left(\frac{P_{r,N}^{S} - c_N}{(1-\alpha)P_f^R}\right)^{\tau} + Q_f^{S,U}\left(\frac{1}{A}\right)^{1+\tau}\left(\frac{P_{r,N}^{S} - c_N}{(1-\alpha)P_f^U}\right)^{\tau}. \tag{28}$$

Analogous to the base without regulations, the derived demand for live hogs can be obtained as follows:

$$Q_f^{D,R} = A\left(\alpha\left(Q_{r,C}^{D,R}\right)^{\rho} + (1-\alpha)\left(Q_{r,N}^{D,R}\right)^{\rho}\right)^{\frac{1}{\rho}}, \tag{29}$$

$$Q_f^{D,U} = A\left(\alpha\left(Q_{r,C}^{D,U}\right)^{\rho} + (1-\alpha)\left(Q_{r,N}^{D,U}\right)^{\rho}\right)^{\frac{1}{\rho}}. \tag{30}$$

Equilibrium Conditions with Regulations

The following sets of conditions characterize the equilibrium quantities, which is analogous to the baseline case:

$$Q_f^{R*} = Q_f^{D,R*} = Q_f^{S,R*}; P_f^{R*} = P_f^{D,R*} = P_f^{S,R*}, \tag{31}$$

[13] Processors who attempted to raise prices for noncovered products would be undercut by processors who did not participate in the restricted market and, thus, did not incur Δc_C.

$$Q_f^{U*} = Q_f^{D,U*} = Q_f^{S,U*}; P_f^{U*} = P_f^{D,U*} = P_f^{S,U*}, \tag{32}$$

$$Q_{r,C}^{R*} = Q_{r,C}^{D,R*} = Q_{r,C}^{S,R*};\; P_{r,C}^{R*} = P_{r,C}^{D,R*} = P_{r,C}^{S,R*}, \tag{33}$$

$$Q_{r,C}^{U*} = Q_{r,C}^{D,U*} = Q_{r,C}^{S,U*};\; P_{r,C}^{U*} = P_{r,C}^{D,U*} = P_{r,C}^{S,U*}, \tag{34}$$

$$Q_{r,N}^{*} = Q_{r,N}^{D*} = Q_{r,N}^{S*};\; P_{r,N}^{*} = P_{r,N}^{D*} = P_{r,N}^{S*}. \tag{35}$$

In equilibrium, production will enter the regulated market of covered products and exit the unregulated market until the return to the marginal entrant is the same regardless of which type of farm raw material is produced. Hence, the following conditions must hold at the farm and retail markets:

$$P_f^{R*} = P_f^{U*} + \sigma^*, \tag{36}$$

$$\frac{Q_{r,C}^{R*}\left(P_{r,C}^{R*} - c_C - \left(\frac{\Delta c}{\mu^*} + \Delta c_C\right)\right) + Q_{r,N}^{R*}\left(P_{r,N}^{*} - c_N\right)}{Q_f^{R*}} = P_f^{R*}, \tag{37}$$

$$\frac{Q_{r,C}^{U*}\left(P_{r,C}^{U*} - c_C\right) + Q_{r,N}^{U*}\left(P_{r,N}^{*} - c_N\right)}{Q_f^{U*}} = P_f^{U*}. \tag{38}$$

New California Pork Regulations and North American Pork Markets

This section provides background for the application of the developed model above. We outline two topics. First, we consider a new law and associated regulations in California that change farm practices allowed within the state and, more importantly, farm practices for raising animals from which derived products are sold in California. Second, we describe crucial features of the pork supply chain in North America (Canada and the United States) that determine the implications of the new California regulations. For this purpose, we administered written surveys and conducted in-person and telephone interviews with key personnel operating at various stages of the supply chain.

New Regulations for California Sows and Pork in the California Markets

Prop 12, which was approved in November 2018 with a 63% favorable vote, decrees that California farms "shall not knowingly cause any covered animal to be confined in a cruel manner" (California Health and Safety Code (HSC) S. 25990). Covered animals include "breeding pigs" for which "confined in a cruel manner" is defined as "confining a breeding pig with less than 24 square feet of usable floor space per pig," with exception granted for brief periods when the sow is farrowing and nursing piglets (HSC S. 25991). Naturally, in the regulations to implement Prop 12, there are specifications about the space allowance precisely when each sow must be granted 24 square feet. Prop 12 set January 1, 2022, at which the new pork regulations go into effect.

There are additional limits on practices with which farms must comply. First, breeding pigs may be confined for farrowing at most five days prior to breeding pigs' expected date of giving birth and while nursing piglets. Second, confinement for animal husbandry treatment is allowed no more than six hours in any 24-hour period and no more than 24 hours total in any 30-day period. Third, starting January 1, 2023, farms must hold a valid certification, which requires compliance, inspections, and recordkeeping.

Even more important than the regulations of farms within California, which has less than 0.1% of the breeding pigs in North America (USDA NASS 2020), are the restrictions on pork products marketed within the state. "A business owner or operator shall not knowingly engage in the sale with the State of California of any whole pork meat that the business owner or operator knows or should know is 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" (HSC

S. 25990).[14] This provision of Prop 12 imposes the housing requirements for sows from which weanling pigs are destined for pork supplying California buyers, not just sow operations based in California.

Prop 12 denotes regulated pork products as "whole pork meat," defined to mean "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" (HSC S. 25991). Because the covered products exclude cooked pork cuts, products such as cooked ready-to-eat ham or pork lunch meats are not in the covered category. This definition of "whole pork meat," explicitly excludes products such as soups, sandwiches, pizzas, hot dogs, or similar processed or prepared food products that contain substantial non-pork food ingredients.

California has adopted detailed regulations to define covered products and implement enforcement.[15] These regulations explicitly state that ground or otherwise comminuted pork, including sausage, is not a "cut" of pork and is therefore also not in the covered product category. Prop 12 enforcement regulations require any pork "handlers" that sell or distribute covered pork products to "end-users" in California to register annually with CDFA. "Handlers" include farms, distributors, warehouses, and co-packers. California "end-users" include consumers, retailers, restaurants, or food manufacturers. The proposed regulations also require registered handlers to be inspected and certified by a CDFA-accredited third-party for compliance with Prop 12 standards. Certified producers and handlers must keep the records for

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[14] Note that the proposition and regulations are framed in terms of a "covered animal," which for pork is a "breeding pig" to include only sows (HSC S. 25991).
[15] The proposed regulations can be accessed at https://www.cdfa.ca.gov/ahfss/pdfs/regulations/AnimalConfinementText1stNotice_05252021.pdf.

two years. Finally, all covered pork products for sale within California must be labeled with “CA 24+ Compliant.”

The North American Pork Supply Chain with Regulations

Figure 2 displays a flow chart of the hog/pork supply chain. The first three stages using rectangular boxes represent stages in hog production. The following two stages show pork processing stages. The next two stages using hexagon boxes represent wholesaling and retailing stages. The last stage in the supply chain indicates final pork consumers.

Hog production involves three stages: farrowing, nursery, and finishing. In the farrowing stage, breeding pigs produce piglets and feed them for about 21 days. The law applies at this stage, with the minimum 24 square-foot space requirement per pig and additional regulations, including no use of gestation stalls, except during a few days before birth and three weeks when piglets remain with their mother pigs after birth.

It will be costly for most farrowing operations to comply with the requirements because they use gestation stalls. Some operations currently confine sows in group pens and will have a cost advantage in converting their operations for compliance. However, among group housing operations, very few operations are fully compliant with Prop 12’s space requirements, so any compliant operation will face substantial one-time costs. Compliant farms will also face higher variable costs because, for example, of increased labor costs and veterinarian service.

After weaning, piglets are transferred to nursery operations and stay there for 6 – 8 weeks. Pigs are then moved to a finishing operation and fed a diet of corn and soybean meal and nutritional supplements for 115 – 120 days before marketing, reaching 270 – 300 pounds.

Prop 12 will not directly regulate nursery and hog feeding operations. However, those operations must pay a higher price for pigs from Prop-12 compliant farrowing operations. Furthermore, because the identity of those pigs must be preserved, they may be segregated before shipping for slaughter.

Primary processors slaughter hogs and produce uncooked cuts of pork and ground pork products. These products are sold to wholesalers, retailers, and foodservice providers, or secondary processors. Among many pork products, uncooked cuts of pork sold in California must come from compliant hogs. However, other pork products do not require Prop 12 compliance. These include ground pork, sausage, and cooked products such as lunch meats and fully cooked hams. Also, Prop 12 does not cover pork used as an ingredient in prepared foods such as hotdogs and pizza and also pork used in uncooked mixed products such as soups and meat mixtures.

For the identity preservation of compliance, compliant hogs and pork products must be segregated from non-compliant ones at any stage of processing and marketing. Operations that sell to retailers will have to create new stock-keeping units (SKUs) for compliant products, imposing another fixed cost. Operations may also need a larger warehouse or extra facilities and equipment to stock and distribute compliant products separately from non-compliant ones.

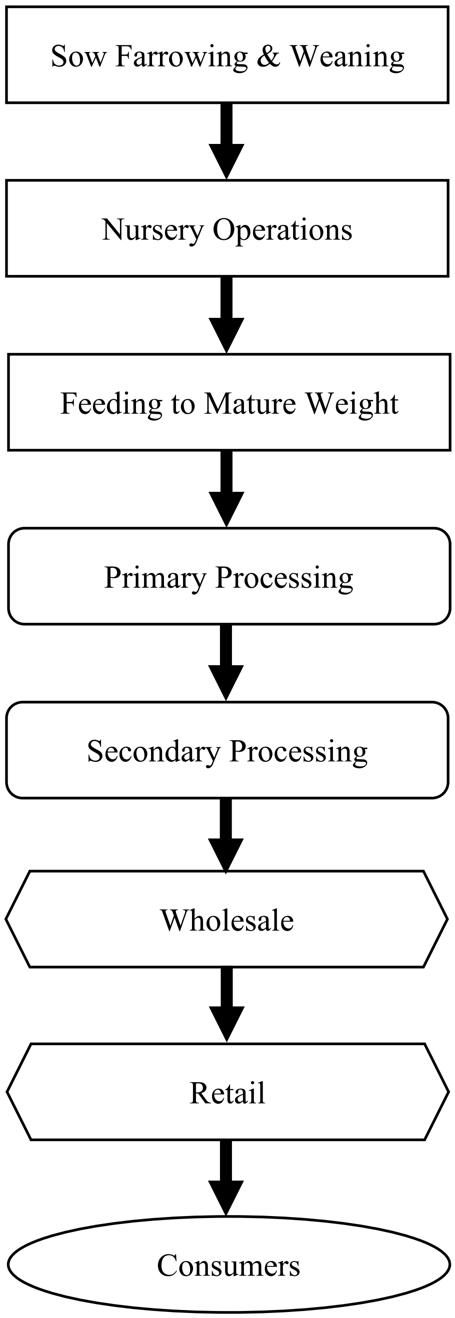

Figure 2. The Hog/Pork Supply Chain

Model Calibration

We use the economic model developed above to simulate the impacts of Prop 12. The model was calibrated around 2018 values for hog production and pork consumption in Canada and the United States. Imports and exports of pork products from the two countries were also incorporated at 2018 values under the assumption that the new trade is perfelctly price inelastic, consistent with prior work (e.g., Wollgenant 1993; Saitone, Sexton, and Sumner 2015).

The parameters (intercepts and slopes) of the primary supply and demand functions were calibrated such that the functions fit the 2018 market values for North America (the United States and Canada), based on Canadian and U.S. government statistics, and have the corresponding price elasticity given those values. We used a price elasticity of supply of hogs at the farm of 1.8, an estimate obtained by Lemieux and Wohlgenant (1989) and used in prior work (e.g., Wohlgenant 1993; Brester, March, and Atwood 2004; Saitone, Sexton, and Sumner 2015).[16] To parameterize the primary demand functions, we began with a base price elasticity of demand for all pork from the recent study by Okrent and Alston (2011), who estimated a retail price elasticity of demand of -0.68 for all pork. This value compares very closely to values of -0.69 and -0.79 used by Buhr (2005) and -0.65 reported by Wohlgenant and Haidacher (1989). The demands for covered and non-covered pork will be more price elastic than the demand for pork as an aggregate category based on consumers' willingness to substitute between the two types of pork products in response to price signals. Based on our review of the relevant literature,

[16] Price elasticity of supply for most products depends upon the length of time producers have to adjust to a price change. In the very short run, there may be little opportunity to adjust production, making supply very unresponsive or inelastic to price changes, but opportunities to adjust production in response to price changes increase as the time horizon is expanded. Saitone, Sexton, and Sumner (2015) utilized the same estimate in their work on the hog industry's response to buyers requiring restricted use of antibiotics in pork production, arguing that this estimate was reflective of an intermediate-run horizon that allowed the industry a range of adjustment to buyers, or in our case, political jurisdictions, requiring the industry to adopt restrictive production practices.

we chose a base value of -0.9 for covered pork and -1.1 for non-covered pork.[17] Given the Okrent and Alston's estimate of the price elasticity of demand for all pork and the market shares, these values imply a cross-price elasticity of 0.36 for non-covered pork demand in response to a change in the price of covered pork and a cross-price elasticity of 0.26 for covered pork demand in response to a change in the price of non-covered pork.

Calibration of the Derived Supply and Demand Functions

The derived supply and demand functions are characterized by five parameters: the processing and marketing margins of the two products, c_C and c_N, the scale parameter, A, the share parameter, α, and the elasticity parameter, ρ.

The difference between the 2018 average retail price and the 2018 average farm price was used to calibrate the per-unit marketing margins, c_C and c_N (each measured in terms of retail weight per cwt.). This calibration approach assumes that the net price of covered pork after excluding the processing and marketing margin, which is $P_{r,C} - c_C$, equals that of non-covered pork, which is $P_{r,N} - c_N$. To check whether this assumption significantly affects simulation results, Appendix D conducted a sensitivity analysis using different ratios of the two expressions, $P_{r,C} - c_C$ and $P_{r,N} - c_N$. The sensitivity analysis shows that simulation results are largely robust to the choices of the ratios.

About the other three parameters, the parameter ρ was calibrated given the elasticity of transformation, τ, and the relation, $\tau = 1/(\rho - 1)$. The share parameter α was calibrated given

[17] We found two studies that addressed demand for individual pork products and estimated the degree of consumer substitution among them in response to price changes. Nayga and Capps (1994) examined the demand for pork products based on data for a single retail store in Houston, Texas. Hailu et al. (2014) studied demand for pork products in Canada based on a panel of Canadian consumers. Both studies showed a modest willingness on consumers' parts to substitute among alternative pork products, but neither study's results were directly relevant to our study.

τ, the output quantities, and the net price of the two products after excluding the marketing margins, $P_{r,C} - c_C$ and $P_{r,N} - c_N$. Finally, the scale parameter A was calibrated given τ, α, and the hog input and output quantities. See Appendix E for detailed calibration procedures. An elasticity of transformation of 0.5 was used to reflect an intermediate-run horizon that allows the intermediaries to adjust production proportions between covered and non-covered pork products. Given the uncertainty regarding the elasticity of transformation, a sensitivity analysis was conducted given different values of the elasticity of transformation and found the robustness of the simulation results (see Appendix F for the sensitivity analysis).

Costs of Compliance with Prop 12

Given the size of the California pork market, about 8-9% of North American sow housing needs to satisfy Prop 12 standards. Most farms use gestation stalls, but about 30% of sows (2.3 million) are in group housing. Because compliance would be less costly for group housing farms than those using gestation stalls, compliant farms will be among those group housing farms. Hence, the one-time cost of conversion applies to operations that currently use group housing but do not satisfy Prop 12's requirements. Variable costs for group housing operations that would become Prop 12 compliant are also compared with those that remained non-compliant.

The most tangible increase in capital recovery costs due to Prop 12 comes from fewer sows using a facility. Based on data from the industry, about 20 square feet of usable space per sow are allowed on average among group housing operations. Hence, fixed costs per sow rise by about 20% to increase the space allowance per sow from 20 to 24 square feet. Based on farm cost data (Tonsor and Reid 2020; Christensen 2021; USDA-ERS 2021), the incremental capital costs were assessed to be $3 per pig.

Although Prop 12 does not directly affect variable costs, it will indirectly affect them. For commercial purposes, the Prop 12 requirements are waived in the following cases: (i) five days prior to the expected farrowing date, (ii) sows are nursing, and (iii) a maximum of six hours per day, not to exceed 24 hours in total over a 30-day period during breeding activities. The limited exemptions restrict standard housing practices. Depending on the health condition, breeding pigs are often confined in farrowing crates for more than five days prior to the birth date. The period around mating is critical for sow reproduction, and prolonged stress can negatively affect sow reproduction during that period (Turner et al. 2005; Knox et al. 2014). After weaning, mixing sows before insemination can cause higher stress than mixing the sows after insemination (Rault et al. 2014). The limited exemptions restrict treatments on breeding pigs during the period around mating, which will decrease the effectiveness of insemination and reproduction. The inefficiency of breeding, farrowing, and nursing were assessed to be about $2 per pig, based on farm cost data (Tonsor and Reid 2020; Christensen 2021; USDA-ERS 2021).

These compliance costs are likely to vary across farms because compliance costs may be attributable to some farm-specific characteristics (perhaps managerial expertise for which the farm earns higher profits). Similarly, some farms may have unique attributes that allow them to earn higher profits than their peers in the market.

A uniform distribution was characterized for the 30% hogs, consistent with the share of current group housing operations in North America. About 70% of the hog production is under stall housing, and they were specified to supply non-compliant hogs. Given that slightly less than 10% of North American hogs are destined for California, farms covering roughly 20% of the total sows might seriously consider the option to produce Prop 12-compliant sows. One way to model the range of farms and the distribution of costs is to treat the calculated value ($5 per head) as roughly the midpoint of the uniform distribution of the first 20% hogs. If the range from \$4 to \$6 per head is taken for the first 20% hogs, this range is equivalent to a percentage increase in marginal cost per weanling pig increase of between about 10% and 14%. Given these conditions, the values were obtained for the lower bound and the upper bound of the distribution, $\underline{\sigma}$ and $\overline{\sigma}$, and the incremental variable costs, ν, using the hundredweight basis ($\underline{\sigma} = \$2.49$ per cwt., $\overline{\sigma} = \$4.35$ per cwt., and $v = \$1.24$ per cwt.).

Additional Costs of Processing and Marketing Prop 12-Compliant Pork

The weanling pigs that leave farrowing operations move through the feeding stages to reach slaughter weights in about five months. Prop 12 requires that hogs destined for California are clearly identified so that the uncooked cuts of pork from these hogs can be segregated, labeled, and traced. Besides identity preservation, there is no difference in how these hogs are housed or fed. Thus, any added costs during the feeding stages are small on a per-hog basis. However, they will likely incur higher transport costs to get their hogs to a processing plant that plans to supply Prop 12-compliant pork.

Given that California only comprises about 11% of the North American retail pork market, many primary processing operations (slaughter plants) will choose not to acquire the costly Prop 12-compliant hogs. These plants will avoid added costs of identifying, segregating, tracing, and labeling the compliant pork separately from the rest of their production.

Those primary processing operations that do acquire and process the more expensive compliant hogs will incur additional costs to assure that they can sell this compliant pork into the California market. Hogs destined for Prop 12-compliant cuts must be identified, segregated, and traced. The compliant hogs will be processed on different days and at different times from other hogs to assure that no non-compliant pork is comingled with uncooked cuts of pork that are destined for the California market.

The most efficient scheduling plan will involve added transport, storage, and scheduling costs for processing California-compliant hogs. Such costs include separate holding pens, more complicated and less flexible scheduling, interruption in plant operation between processing the compliant and non-compliant hogs, additional storage capacity so that the up-to-double SKUs of fresh pork can be kept in distinct lots, a more complicated labeling process, and more complex shipping of labeled products. The costliest among these factors is likely to be the interruption of plant operations and reduced throughput during the change-over from compliant to non-compliant hogs and pork. The additional cost is assessed to be about $15 per compliant hog slaughtered.

In addition to higher costs at the primary processing plants, there will be additional costs for handling compliant pork throughout the downstream marketing chain. These costs are estimated to be about $0.05 per pound of Prop 12-compliant uncooked cuts of pork, based on discussions with secondary processors and marketers.[18]

Simulation Results

Impacts of Proposition 12 on Hog and Pork Prices and Outputs, Producer Surplus, and Consumer Surplus

Table 1 presents the results. The model projects that the average farm price equivalent of Prop 12-compliant pork will rise by 3.5%, or about $2.74 per hundredweight (cwt). However, it

[18] Breeding sows themselves eventually are slaughtered, although their meat is not often used to produce covered pork products. In any event, compliant breeding sows would not produce California-compliant products unless their mothers had been California compliant.

projects almost no change in the price of non-compliant hogs or pork. Further, it projects that the average price of uncooked cuts of pork in California (the regulated products) will rise by 7.2%, or about $0.24 per pound. Finally, the model projects almost no change in the retail price of pork outside California or in the price of pork products not covered under Prop 12.

The simulation results suggest that the total quantity of live hogs will not significantly change because of Prop 12. However, the share of live hogs whose pork products are destined for California will decline from 8.9% to 8.3% of North American hogs. California consumers will eat 5.9% less of the regulated, uncooked cuts of pork as a consequence of Prop 12. Quantity impacts for uncooked cuts of pork for the rest of North America and for all other pork products, for which Prop 12 compliance is not required, will be negligible.

The producer surplus change among converters for Prop 12 compliance is estimated to be positive (about $28 million annually). Those who continue to produce for the unregulated market will lose – about a producer surplus loss of $52 million annually. The producer surplus change for all producers will be slightly negative (about $23 million loss annually). Despite industry opposition, Prop 12 is projected not to impose much negative impact on producers.

California pork consumers lose mainly because they will pay more for uncooked cuts of pork, but they will buy less. Simulations show that the economic benefits for California consumers from buying pork will decline by about $298 million annually.

The impact of Prop 12 on pork consumers outside California will be minimal (about $86 million annually), considering the market size of the rest of North America, because Prop 12 will cause only tiny changes to prices and outputs. Note that the estimate of consumer loss does not account for the possibility that fewer pork products will be sold in California after the implementation of Prop 12 because it will not be worth the cost to introduce new SKUs for niche products.

Finally, note that the model and simulation results do not incorporate impacts of temporary undersupplies or oversupplies of Prop 12-compliant pork caused by uncertainties about the needed adjustments and resolutions of legal challenges. There will likely be a transition period after January 1, 2022, during which markets will not yet have settled on the equilibrium price and quantity impacts.

Table 6.1. Impacts of Proposition 12 on Hog and Pork Prices and Outputs, Producer Surplus, and Consumer Surplus

Variable	Unit	Base	Prop 12	Percent Change
Prices				
Average price, all slaughter hogs	$/cwt	79.20	79.21	0.0
Price, hogs for California pork	$/cwt	79.20	81.94	3.5
Price, hogs for non-California pork	$/cwt	79.20	78.96	-0.3
Average retail price, uncooked cuts of pork	$/lb	3.30	3.32	0.6
Retail price, California uncooked cuts	$/lb	3.30	3.54	7.2
Retail price, non-California uncooked cuts	$/lb	3.30	3.29	-0.2
Retail price, non-covered pork	$/lb	3.79	3.79	0.1
Quantities				
Retail weight, hogs slaughtered	million cwt	233.1	232.6	-0.2
Share of hogs for the California market	%	8.9	8.3	-6.4
Share of uncooked pork cuts in compliant hog carcass	%	63.1	63.6	0.8
Retail uncooked pork cuts	billion lb	11.95	11.89	-0.5
California retail uncooked pork cuts	billion lb	1.30	1.23	-5.9
Non-California retail uncooked pork cuts	billion lb	10.65	10.66	0.1
Retail non-covered pork	billion lb	8.55	8.55	0.1
Producer and Consumer Surplus Changes				
Producer surplus change, Prop 12 converters	$ million		28.5	
Producer surplus change, non-converters	$ million		-51.5	
Producer surplus change, total	$ million		-23.0	
Consumer surplus change, California	$ million		-298.2	
Consumer surplus change, non-California	$ million		85.8	
Consumer surplus change, total	$ million		-212.4	

Notes: cwt=hundredweight. Prop 12 requires that uncooked cuts of pork sold in California must come from compliant hogs. However, it does not cover other pork products, which denotes "non-covered pork" in this table.

Implications of Proposition 12 about Treatment of Pigs at Farms

Although one major requirement of Prop 12 is no use of gestation stalls, Prop 12 will hardly affect the conversion of stall housing operations. About 8-9% of the North American hog production is needed for the California market. However, about 30% of breeding pigs in North America are already confined in group housing, implying a substantial share of pork products already come from breeding pigs in group housing. A sufficient share of these pork products will be diverted for the California market under Prop 12. So, California's prohibition of selling uncooked cuts of pork from breeding pigs confined in stall housing will hardly get those pigs out of stalls in North America.

Instead, Prop 12 will provide slightly more space to breeding pigs confined in converters currently using group housing because the space allowance per sow in typical group housing is usually smaller (on average, about 20 square feet per sow) than California's minimum requirement (at least 24 square feet per sow). According to simulations, 8.3% of hogs are needed for the California market, implying the same share of sows are needed. Considering about 7.6 million sows in North America, about 630 thousand sows will be confined under California's housing standards. That is, California pork consumers will pay about $298 million annually to provide 4 square feet more per sow on average for about 630 thousand sows in North America.

Now investigate the impact of Prop 12 on the total space allowance in the North American production. As the first step, assess the total space allowance before the imposition of the regulations. About 7.6 million breeding pigs are in North America, and 70% of them, which is about 5.32 million breeding pigs, are allowed 14 square feet of space per pig on average. The rest of breeding pigs, about 2.28 million pigs, are in typical group housing (20 square feet of space per pig on average). Then, in total, the space allowance is about 120.1 million square feet before the regulations.

Next, now let us consider the space allowance after the imposition of the regulations. Based on the simulations, the total number of breeding pigs fall about 0.2%, which implies about 7.58 million pigs in the North American production after the imposition of Prop 12. About 70% of breeding pigs are assumed to be still in stall housing, which implies about 5.31 million pigs. The rest of pigs are in group housing, but, as explained in the previous paragraph, about 630 thousand pigs are in California's standards with 24 square feet of space, which implies about 1.65 million pigs are in typical group housing (20 square feet of space on average). Then, the total space allowance in the North American production is about 122.4 million square feet after the imposition of the regulations, which is about a 1.9% increase in the total space allowance by the regulations.

The set of regulations specified by Prop 12 is not the only option of policy instruments that allow more space for farm animals. The number of breeding pigs treated by regulations would differ by how regulations are designed. For illustration, one alternative policy is explored: The California government would raise a general fund to directly subsidize farms that convert their housing practices.

The subsidies could be distributed through a second-price auction. Each farrowing operation could submit a bid of how much it needed to be compensated per sow per year to convert its operation to Prop 12 compliant housing. Under a second-price auction, each farm has incentive to bid its valuation. Specifically, under the conversion continuum specified in the economic model, each farm i bids $\sigma_i \times n_i$ with low bids accepted and paid a conversion fee equal to the lowest unsuccessful bid, where the term σ_i is the annual average conversion cost per hog and n_i is the total number of hogs per sow per year. The auction accepts bids until the tax revenue is exhausted. Suppose that R tax revenues are raised. Then, the payment per converting sow is R/N^* where N^* is the number of sows that convert such that it is just the total number of breeding sows, N, in the North American market times the fraction that converts. For simplicity, assume that the number of hogs per sow per year, n_i is the same over the converters, which is $\bar{n}$. Then, this expression needs to equal to the bid price of the marginal converter:

$$\frac{R}{N \times \bar{n} \times \frac{\sigma^A - \underline{\sigma}}{\overline{\sigma} - \underline{\sigma}}} = \sigma^A \tag{6.1}$$

Given all of the values in this expression except for σ^A, the expression can be solved for σ^A to determine how many hogs can move from existing housing into Prop 12-compliant housing and compare it to the number from Prop 12. Specifically, R is \$297 million, N is 7.6 million sows, $\bar{n}$ is 22 pigs per sow, $\underline{\sigma}$ is \$2.41 per pig, and $\overline{\sigma}$ is \$4.35 per pig. After steps of algebra, the solution of σ^A is obtained to be \$6.67 per pig. That is, the alternative policy could cover about 29% of the total hog production or about 2.2 million sows, which is greater than the number of sows covered by Prop 12 in simulations (630 thousand sows).

The alternative policy is fundamentally different from Prop 12 and, more generally, regulations on products sold within local jurisdictions. Under the alternative policy, there is no need to endure the costs of segregation and other compliance costs at the processing and subsequent downstream stages, which implies no significant price and quantity changes along the pork supply chain. California pork consumers buy and eat the same pork as everyone else but contribute to the government fund.[19]

[19] Someone could argue that this is not the same as Prop 12 because California consumers would know they were helping get breeding pigs out of crates, but the chop they eat may well still come from a crated sow because all pork

Another important implication is about who pays the regulation costs among Californians. As discussed above, because the regulation costs of Prop 12 are mainly transferred through the retail price of covered pork at the California market, most regulation costs will be paid by California consumers buying covered pork. However, all citizens were allowed to vote, not just those who eat uncooked cuts of pork. Some supporters of Prop 12 are vegans or do not consume uncooked cuts of pork for other reasons. Hence, there is inconsistency between who supports Prop 12 and who pays the costs of Prop 12 among Californians. Under a general government fund, however, the regulation costs are distributed across all Californian taxpayers, rather than pork consumers. This example illustrates that inconsistency between the supporters and the cost-takers depends on how policy instruments are designed, which often receives relatively small attention in the literature.

Conclusions

For political, jurisdictional, and technical reasons, regulations associated with pollutions and other externality issues in agricultural production have often been implemented by local jurisdictions. A major group of those regulations is local mandates on farm production practices. Another group of regulations gaining popularity are restrictions on farm production practices for products sold within a local jurisdiction. The two groups of regulations are fundamentally different from each other. The former group of regulations creates heterogeneous production costs and alters the comparative advantage of different production regions but generally will not affect downstream operations by requiring segregation, traceability, etc. Most often, the product emerging from different regulatory jurisdictions will be comingled at some point in the

is bought and sold in the same manner. If consumers cared not just about breeding pigs but whether the pork was animal friendly, then Prop 12 and the alternative policy are not the same.

processing and distribution. This paper explores the economic implications of the latter group of regulations, distinctive from mandates on farm production practices, by analyzing the impact of California Proposition 12 on the North American pork supply chain.

This paper can make contributions to the analysis of mandates. The model allows the heterogeneity in the costs of meeting the mandate and innovatively studies the case where a mandate only applies to a portion of the output of the live animal. To reflect an intermediate-run responses to the regulations along the pork supply chain, the model allows capital conversion for compliance at farms and variable production proportions between covered and non-covered pork in processing farm raw materials. This research demonstrates how these aspects interact and drive substantial price and quantity adjustments along vertically linked markets and across geographically different markets.

Simulations show that, despite industry opposition, the mandates likely do not impose much negative effect on producers in North America. However, the mandates generate a modest consumer welfare loss (about $298 million annually) in California. Despite the substantial regulation costs, Prop 12 will hardly make stall housing operations adopt California's standards. A substantial percentage of pork products already come from breeding pigs confined in group housing operations. These pork products will be diverted for the California market under Prop 12, so this law will hardly get breeding pigs out of stall housing. Because California's standards are stricter than typical group housing, breeding pigs confined in converters will have slightly more space than before.

Prop 12 and, more generally, the regulations on products sold in local jurisdictions are not a unique policy instrument that allows more space for farm animals. To illustrate, this research considers another policy option that the California government would raise a general fund to directly subsidize farms that convert their housing practices. Under a setup comparable to Prop 12, the alternative policy can achieve a greater increase in the number of animals confined in California's standards than Prop 12. This example illustrates that Prop 12 and, more broadly, regulations imposed at the point of purchase may not be an efficient way to convert conventional farming practices because they raise costs at downstream stages along the supply chain as well as at farm.

This research can be extended in several important ways in order to further questions. First, the model assumes that consumers are indifferent between products produced under the restricted practices and the other products. However, some consumers may pay extra for products produced under restricted practices. To reflect such a potential demand shift, one may refine the representation of the market demand functions. Second, this research considers a direct subsidy for farms, funded by a lump-sum tax, as an alternative policy. One may formally compare several plausible alternative policies, including an excise tax or a quota on products sold within the regulated jurisdiction, to obtain a comprehensive understanding of cost effectiveness by policy instruments.

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Supplementary Materials

Appendix A. Two Special Cases of the Constant Elasticity of Transformation Production Possibility Frontier

We consider the following constant elasticity of transformation production possibility frontier (equation 4 in the paper):

$$q_f = A\left(\alpha\left(q_{r,C}\right)^{\rho} + (1-\alpha)\left(q_{r,N}\right)^{\rho}\right)^{\frac{1}{\rho}}. \tag{A.1}$$

The parameter A is a scale parameter where $A > 0$, the term α is a share parameter where $0 < \alpha < 1$, and the term ρ is a parameter that determines the elasticity of transformation τ where $1 < \rho < \infty$ and $\tau = 1/(\rho - 1)$. As $\rho \to 1$, the CET frontier approaches perfect transformation:

$$q_f = A\left(\alpha q_{r,C} + (1-\alpha) q_{r,N}\right). \tag{A.2}$$

Now let us consider the case when $\rho \to \infty$. Equation (A1) yields an indeterminate form, which is ∞^0, as $\rho \to \infty$. To explore this indeterminate form, we will use the L'Hopital's rule. For this purpose, first, take the logarithm:

$$\ln q_f = \ln A + \frac{1}{\rho}\ln\left(\alpha\left(q_{r,C}\right)^{\rho} + (1-\alpha)\left(q_{r,N}\right)^{\rho}\right). \tag{A.3}$$

Let us focus on the second term on the right-hand side. According to the L'Hopital's rule, the following relation holds:

$$\begin{aligned}&\lim_{\rho\to\infty}\frac{1}{\rho}\ln\left(\alpha\left(q_{r,C}\right)^{\rho} + (1-\alpha)\left(q_{r,N}\right)^{\rho}\right)\\ &= \lim_{\rho\to\infty}\frac{\alpha\left(q_{r,C}\right)^{\rho}\ln\left(q_{r,C}\right) + (1-\alpha)\left(q_{r,N}\right)^{\rho}\ln\left(q_{r,N}\right)}{\alpha\left(q_{r,C}\right)^{\rho} + (1-\alpha)\left(q_{r,N}\right)^{\rho}}.\end{aligned} \tag{A.4}$$

Let us define $M \equiv \max\left(q_{r,C}, q_{r,N}\right)$ where $M > 0$. Dividing both the numerator and denominator by M^{ρ},

$$\lim_{\rho\to\infty} \frac{\alpha\left(q_{r,C}\right)^{\rho}\ln\left(q_{r,C}\right)+(1-\alpha)\left(q_{r,N}\right)^{\rho}\ln\left(q_{r,N}\right)}{\alpha\left(q_{r,C}\right)^{\rho}+(1-\alpha)\left(q_{r,N}\right)^{\rho}}$$

$$= \lim_{\rho\to\infty} \frac{\alpha\left(\frac{q_{r,C}}{M}\right)^{\rho}\ln\left(q_{r,C}\right)+(1-\alpha)\left(\frac{q_{r,N}}{M}\right)^{\rho}\ln\left(q_{r,N}\right)}{\alpha\left(\frac{q_{r,C}}{M}\right)^{\rho}+(1-\alpha)\left(\frac{q_{r,N}}{M}\right)^{\rho}}. \quad \text{(A. 5)}$$

Without loss of generality, assume $q_{r,C} > q_{r,N}$. Because $M = \max\left(q_{r,C}, q_{r,N}\right)$, the term $\left(q_{r,C}/M\right)^{\rho} \to 1$ and $\left(q_{r,N}/M\right)^{\rho} \to 0$ as $\rho \to \infty$. Then,

$$\lim_{\rho\to\infty} \frac{\alpha\left(\frac{q_{r,C}}{M}\right)^{\rho}\ln\left(q_{r,C}\right)+(1-\alpha)\left(\frac{q_{r,N}}{M}\right)^{\rho}\ln\left(q_{r,N}\right)}{\alpha\left(\frac{q_{r,C}}{M}\right)^{\rho}+(1-\alpha)\left(\frac{q_{r,N}}{M}\right)^{\rho}} = \lim_{\rho\to\infty}\frac{\alpha\ln\left(q_{r,C}\right)}{\alpha} = \ln\left(q_{r,C}\right) = \ln M\,. \quad \text{(A. 6)}$$

Similarly, we can obtain the same result when $q_{r,C} \leq q_{r,N}$. Then, from (A2), $\ln q_f = \ln A + \ln M = \ln AM$. Or,

$$q_f = AM = A\max\left(q_{r,C}, q_{r,N}\right). \quad \text{(A. 7)}$$

Hence, as $\rho \to \infty$, the CET frontier approaches fixed proportions.

Appendix B. Derivation of the Supply Functions of Hog Carcass Used for Covered and Non-Covered Pork

Processing plants maximize the revenue of their two outputs:

$$\max_{q_{r,C},q_{r,N}} \left(P_{r,C}-c_C\right)q_{r,C}+\left(P_{r,N}-c_N\right)q_{r,N} \text{ subject to}$$

$$\bar{q}_f = A\left(\alpha\left(q_{r,C}\right)^{\rho}+(1-\alpha)\left(q_{r,N}\right)^{\rho}\right)^{\frac{1}{\rho}} \text{ where } A>0, 0<\alpha<1, \text{and } 1<\rho<\infty. \quad \text{(B.1)}$$

From the Lagrangian

$$\Lambda = \left(P_{r,C}-c_C\right)q_{r,C}+\left(P_{r,N}-c_N\right)q_{r,N}-\lambda\left(A\left(\alpha\left(q_{r,C}\right)^{\rho}+(1-\alpha)\left(q_{r,N}\right)^{\rho}\right)^{\frac{1}{\rho}}-\bar{q}_f\right). \quad \text{(B.2)}$$

The first order conditions are

$$\frac{\partial\Lambda}{\partial q_{r,C}} = \left(P_{r,C}-c_C\right)-\lambda A\left(\frac{1}{\rho}\right)\left(\alpha\left(q_{r,C}\right)^{\rho}+(1-\alpha)\left(q_{r,N}\right)^{\rho}\right)^{\frac{1}{\rho}-1}\alpha\rho\left(q_{r,C}\right)^{\rho-1}=0, \quad \text{(B.3)}$$

$$\frac{\partial\Lambda}{\partial q_{r,N}} = \left(P_{r,N}-c_N\right)-\lambda A\left(\frac{1}{\rho}\right)\left(\alpha\left(q_{r,C}\right)^{\rho}+(1-\alpha)\left(q_{r,N}\right)^{\rho}\right)^{\frac{1}{\rho}-1}(1-\alpha)\rho\left(q_{r,N}\right)^{\rho-1}=0, \quad \text{(B.4)}$$

$$\frac{\partial\Lambda}{\partial\lambda} = -\left(A\left(\alpha\left(q_{r,C}\right)^{\rho}+(1-\alpha)\left(q_{r,N}\right)^{\rho}\right)^{\frac{1}{\rho}}-\bar{q}_f\right)=0. \quad \text{(B.5)}$$

From (B.3) and (B.4), we obtain

$$\frac{P_{r,C}-c_C}{P_{r,N}-c_N}=\frac{\alpha}{1-\alpha}\left(\frac{q_{r,C}}{q_{r,N}}\right)^{\rho-1}. \quad \text{(B.6)}$$

Or,

$$q_{r,N}=\left(\frac{\alpha}{1-\alpha}\frac{P_{r,N}-c_N}{P_{r,C}-c_C}\right)^{\frac{1}{\rho-1}}q_{r,C}. \quad \text{(B.7)}$$

Substituting $q_{r,N}$ from (B.7) for $q_{r,N}$ in (B.5) yields

$$\bar{q}_f = A\left(\alpha\left(q_{r,C}\right)^{\rho}+(1-\alpha)\left(\frac{\alpha}{1-\alpha}\frac{P_{r,N}-c_N}{P_{r,C}-c_C}\right)^{\frac{\rho}{\rho-1}}\left(q_{r,C}\right)^{\rho}\right)^{\frac{1}{\rho}}. \quad \text{(B.8)}$$

After steps of algebra, we obtain

$$q_{r,C} = \frac{\bar{q}_f}{A}\left(\alpha + (1-\alpha)\left(\frac{\alpha}{1-\alpha}\frac{P_{r,N}-c_N}{P_{r,C}-c_C}\right)^{\frac{\rho}{\rho-1}}\right)^{-\frac{1}{\rho}}. \tag{B.9}$$

Because (B.9) is satisfied for every $\bar{q}_f$,

$$q_{r,C} = \frac{q_f}{A}\left(\alpha + (1-\alpha)\left(\frac{\alpha}{1-\alpha}\frac{P_{r,N}-c_N}{P_{r,C}-c_C}\right)^{\frac{\rho}{\rho-1}}\right)^{-\frac{1}{\rho}}. \tag{B.10}$$

The relation, $\tau = 1/(\rho-1)$, yields:

$$q_{r,C} = \frac{q_f}{A}\left(\alpha + (1-\alpha)\left(\frac{\alpha}{1-\alpha}\frac{P_{r,N}-c_N}{P_{r,C}-c_C}\right)^{\tau+1}\right)^{-\frac{\tau}{\tau+1}}. \tag{B.11}$$

(B.11) is the output-constant industry supply of the hog carcass used for uncooked cuts of pork. Because of the homogeneity among intermediaries, we obtain the derived supply function of uncooked cuts of pork as follows:

$$Q_{r,C} = \frac{Q_f}{A}\left(\alpha + (1-\alpha)\left(\frac{\alpha}{1-\alpha}\frac{P_{r,N}-c_N}{P_{r,C}-c_C}\right)^{\tau+1}\right)^{-\frac{\tau}{\tau+1}}. \tag{B.12}$$

This is the expression of equation (6). Similarly, we can obtain the derived supply function of non-covered pork as follows:

$$Q_{r,N} = \frac{Q_f}{A}\left((1-\alpha) + \alpha\left(\frac{1-\alpha}{\alpha}\frac{P_{r,C}-c_C}{P_{r,N}-c_N}\right)^{\tau+1}\right)^{-\frac{\tau}{\tau+1}}. \tag{B.13}$$

(B.13) is the expression of equation (7).

Appendix C. Derivation of the Supply Function of Hog Carcass Used for Covered Pork as a Function of the Price of Live Hogs

The price of live hogs, P_f, is the average of $P_{r,C} - c_C$ and $P_{r,N} - c_N$, weighted by the corresponding quantity shares:

$$P_f = \frac{Q_{r,C}\left(P_{r,C} - c_C\right) + Q_{r,N}\left(P_{r,N} - c_N\right)}{Q_f}. \qquad (\mathrm{C}.1)$$

Using the derived supply functions of covered and non-covered pork, we obtain

$$P_f = \frac{\left(P_{r,C} - c_C\right)\frac{Q_f}{A}\left(\frac{P_{r,C} - c_C}{\alpha}\right)^{\frac{1}{\rho-1}} T + \left(P_{r,N} - c_N\right)\frac{Q_f}{A}\left(\frac{P_{r,N} - c_N}{1-\alpha}\right)^{\frac{1}{\rho-1}} T}{Q_f}$$

$$= \left(P_{r,C} - c_C\right)\frac{1}{A}\left(\frac{P_{r,C} - c_C}{\alpha}\right)^{\frac{1}{\rho-1}} T + \left(P_{r,N} - c_N\right)\frac{1}{A}\left(\frac{P_{r,N} - c_N}{1-\alpha}\right)^{\frac{1}{\rho-1}} T$$

$$= \frac{T}{A}\left(\left(P_{r,C} - c_C\right)\left(\frac{P_{r,C} - c_C}{\alpha}\right)^{\frac{1}{\rho-1}} + \left(P_{r,N} - c_N\right)\left(\frac{P_{r,N} - c_N}{1-\alpha}\right)^{\frac{1}{\rho-1}}\right)$$

$$= \frac{T}{A}\left(\alpha\frac{P_{r,C} - c_C}{\alpha}\left(\frac{P_{r,C} - c_C}{\alpha}\right)^{\frac{1}{\rho-1}} + (1-\alpha)\frac{P_{r,N} - c_N}{1-\alpha}\left(\frac{P_{r,N} - c_N}{1-\alpha}\right)^{\frac{1}{\rho-1}}\right)$$

$$= \frac{T}{A}\left(\alpha\left(\frac{P_{r,C} - c_C}{\alpha}\right)^{\frac{\rho}{\rho-1}} + (1-\alpha)\left(\frac{P_{r,N} - c_N}{1-\alpha}\right)^{\frac{\rho}{\rho-1}}\right),$$

where

$$T = \left(\alpha\left(\frac{P_{r,C} - c_C}{\alpha}\right)^{\frac{\rho}{\rho-1}} + (1-\alpha)\left(\frac{P_{r,N} - c_N}{1-\alpha}\right)^{\frac{\rho}{\rho-1}}\right)^{-\frac{1}{\rho}}.$$

Because $T^{-\rho} = \alpha\left(\frac{P_{r,C}-c_C}{\alpha}\right)^{\frac{\rho}{\rho-1}} + (1-\alpha)\left(\frac{P_{r,N}-c_N}{1-\alpha}\right)^{\frac{\rho}{\rho-1}}$, we obtain

$$P_f = \frac{T}{A} T^{-\rho} = \frac{T^{1-\rho}}{A} = \frac{1}{A}\left(\alpha \left(\frac{P_{r,C} - c_C}{\alpha}\right)^{\frac{\rho}{\rho-1}} + (1-\alpha)\left(\frac{P_{r,N} - c_N}{1-\alpha}\right)^{\frac{\rho}{\rho-1}}\right)^{\frac{\rho-1}{\rho}}.$$

Note that $\left(\frac{1}{\gamma}\right)^{\frac{1}{\rho-1}}\left(\frac{1}{P_f}\right)^{\frac{1}{\rho-1}} = T$. Hence, the supply function of covered pork can be written as:

$$Q_{r,C} = \frac{Q_f}{A}\left(\frac{P_{r,C} - c_C}{\alpha}\right)^{\frac{1}{\rho-1}}\left(\frac{1}{A}\right)^{\frac{1}{\rho-1}}\left(\frac{1}{P_f}\right)^{\frac{1}{\rho-1}} = Q_f\left(\frac{1}{A}\right)^{\frac{\rho}{\rho-1}}\left(\frac{P_{r,C} - c_C}{\alpha}\right)^{\frac{1}{\rho-1}}\left(\frac{1}{P_f}\right)^{\frac{1}{\rho-1}}.$$

Because we know $\tau = 1/(\rho - 1)$, the supply function of covered pork can be rewritten as:

$$Q_{r,C} = Q_f\left(\frac{1}{A}\right)^{1+\tau}\left(\frac{P_{r,C} - c_C}{\alpha P_f}\right)^{\tau}. \tag{C.2}$$

This is the expression of equation (8). Similarly, we can derive the derived supply function of non-covered pork, equation (9).

Appendix D. Robustness of Simulation Results by Different Specification of the Derived Supply and Demand Functions

The per-unit marketing margins of the two products, c_C and c_N are the parameters of the derived supply and demand functions. The two parameters were calibrated, based on the difference between the average retail price and the average farm price, which is $c_C = P_{r,C} - P_f$ and $c_N = P_{r,N} - P_f$ where $P_{r,C}$ is the retail price of uncooked pork cuts, $P_{r,N}$ is that of non-covered pork, and P_f is the farm price. This approach assumes that the net price of each product after excluding its marketing margin is identical between the two products, which implies $P_{r,C} - c_C = P_{r,N} - c_N$.

To check whether this assumption substantially affects simulation results, a sensitivity analysis was conducted given three different values (0.95, 1.00, and 1.05) of the ratio between the two net prices, which is $\psi = (P_{r,C} - c_C)/(P_{r,N} - c_N)$. The following table shows that simulation results are largely robust to the choices under consideration.

Table D.1. Simulated Market Outcomes under Proposition 12 by Different Specification of the Derived Supply and Demand Functions

Variable	Unit	Values of ψ		
		0.95	1.00	1.05
Prices				
Average price, all slaughter hogs	\$/cwt	79.21	79.21	79.20
Price, hogs for California pork	\$/cwt	81.95	81.94	81.94
Price, hogs for non-California pork	\$/cwt	78.96	78.96	78.96
Average retail price, uncooked cuts of pork	\$/lb	3.32	3.32	3.32
Retail price, California uncooked cuts	\$/lb	3.54	3.54	3.54
Retail price, non-California uncooked cuts	\$/lb	3.29	3.29	3.29
Retail price, non-covered pork	\$/lb	3.79	3.79	3.79
Quantities				
Retail weight, hogs slaughtered	million cwt	232.6	232.6	232.6
Share of hogs for the California market	%	8.3	8.3	8.3
Share of uncooked pork cuts in compliant hog carcass	%	63.6	63.6	63.6
Retail uncooked pork cuts	billion lb	11.89	11.89	11.89
California retail uncooked pork cuts	billion lb	1.23	1.23	1.23
Non-California retail uncooked pork cuts	billion lb	10.66	10.66	10.66
Retail non-covered pork	billion lb	8.55	8.55	8.55

Producer and Consumer Surplus Changes				
Producer surplus change, Prop 12 converters	$ million	28.5	28.5	28.4
Producer surplus change, non-converters	$ million	-51.0	-51.5	-52.0
Producer surplus change, total	$ million	-22.5	-23.0	-23.6
Consumer surplus change, California	$ million	-298.2	-298.2	-298.2
Consumer surplus change, non-California	$ million	85.5	85.8	86.2
Consumer surplus change, total	$ million	-212.7	-212.4	-212.0

Notes: cwt=hundredweight. Prop 12 requires that uncooked cuts of pork sold in California must come from compliant hogs. However, it does not cover other pork products, which denotes "non-covered pork" in this table. The term ψ is the ratio between (i) the net price of covered pork after excluding its marketing margin and (ii) the net price of non-covered pork. The base case is $\psi = 1.00$.

Appendix E. Derivation of Relations to Calibrate the Parameters of the CET Production Possibility Frontier

The goal is to express the parameter α as a function of other parameters and variables evaluated at the baseline. The derivation starts with one of the first order conditions of the profit maximization problem of the intermediaries (which is equation (B.7) in Appendix B):

$$q_{r,N} = \left(\frac{\alpha}{1-\alpha}\frac{P_{r,N}-c_N}{P_{r,C}-c_C}\right)^{\frac{1}{\rho-1}} q_{r,C}.$$

The homogeneity among producers yields,

$$Q_{r,N} = \left(\frac{\alpha}{1-\alpha}\frac{P_{r,N}-c_N}{P_{r,C}-c_C}\right)^{\frac{1}{\rho-1}} Q_{r,C}. \tag{E.1}$$

Then,

$$Q_{r,N} = \left(\frac{\alpha}{1-\alpha}\frac{P_{r,N}-c_N}{P_{r,C}-c_C}\right)^{\frac{1}{\rho-1}} Q_{r,C}$$

$$\Leftrightarrow \frac{Q_{r,N}}{Q_{r,C}} = \left(\frac{\alpha}{1-\alpha}\frac{P_{r,N}-c_N}{P_{r,C}-c_C}\right)^{\frac{1}{\rho-1}}$$

$$\Leftrightarrow \left(\frac{Q_{r,N}}{Q_{r,C}}\right)^{\rho-1} = \frac{\alpha}{1-\alpha}\frac{P_{r,N}-c_N}{P_{r,C}-c_C}$$

$$\Leftrightarrow \frac{1-\alpha}{\alpha} = \left(\frac{Q_{r,C}}{Q_{r,N}}\right)^{\rho-1}\frac{P_{r,N}-c_N}{P_{r,C}-c_C}$$

$$\Leftrightarrow \frac{1}{\alpha} = 1 + \left(\frac{Q_{r,C}}{Q_{r,N}}\right)^{\rho-1}\frac{P_{r,N}-c_N}{P_{r,C}-c_C}$$

$$\Leftrightarrow \alpha = \frac{1}{1 + \left(\frac{Q_{r,C}}{Q_{r,N}}\right)^{\rho-1}\frac{P_{r,N}-c_N}{P_{r,C}-c_C}} = \frac{\frac{P_{r,C}-c_C}{\left(Q_{r,C}\right)^{\rho-1}}}{\frac{P_{r,C}-c_C}{\left(Q_{r,C}\right)^{\rho-1}} + \frac{P_{r,N}-c_N}{\left(Q_{r,N}\right)^{\rho-1}}}.$$

Because $\tau = 1/(\rho - 1)$,

$$\alpha = \frac{\dfrac{P_{r,C} - c_C}{\left(Q_{r,C}\right)^{\frac{1}{\tau}}}}{\dfrac{P_{r,C} - c_C}{\left(Q_{r,C}\right)^{\frac{1}{\tau}}} + \dfrac{P_{r,N} - c_N}{\left(Q_{r,N}\right)^{\frac{1}{\tau}}}}. \tag{E.2}$$

Given the calibrated α, the scale parameter A can be calibrated, given the CET production possibility frontier:

$$A = \frac{Q_f}{\left(\alpha\left(Q_{r,C}\right)^{\rho} + (1-\alpha)\left(Q_{r,N}\right)^{\rho}\right)^{\frac{1}{\rho}}}. \tag{E.3}$$

Appendix F. Economic Effects of Proposition 12 Using Different Values of the Elasticity of Transformation

Covered and non-covered pork were allowed to be produced under variable proportions. For this purpose, the model allows a constant elasticity of transformation (CET) function. A key parameter of the CET function is the elasticity of transformation, denoted by τ. It was assessed to be 0.5 for simulations to reflect an intermediate-run horizon.

Because of uncertainty about τ, a sensitivity analysis was conducted given different values of the elasticity of transformation, 0.2, 0.5, and 1.0. Table F.1 reports the simulated prices, quantities, and producer surplus changes, and consumer surplus changes by different values of the elasticity of transformation. The simulation results are robust to different values of the elasticity of transformation.

Table F.1. Simulated Market Outcomes under Proposition 12 by Different Values of the Elasticity of Transformation

Variable	Unit	Values of τ		
		0.2	0.5	1.0
Prices				
Average price, all slaughter hogs	$/cwt	79.21	79.21	79.21
Price, hogs for California pork	$/cwt	81.94	81.94	81.94
Price, hogs for non-California pork	$/cwt	78.96	78.96	78.96
Average retail price, uncooked cuts of pork	$/lb	3.32	3.32	3.32
Retail price, California uncooked cuts	$/lb	3.54	3.54	3.54
Retail price, non-California uncooked cuts	$/lb	3.29	3.29	3.29
Retail price, non-covered pork	$/lb	3.80	3.79	3.79
Quantities				
Retail weight, hogs slaughtered	million cwt	232.6	232.6	232.6
Share of hogs for the California market	%	8.3	8.3	8.2
Share of uncooked pork cuts in compliant hog carcass	%	63.2	63.6	64.2
Retail uncooked pork cuts	billion lb	11.90	11.89	11.89
California retail uncooked pork cuts	billion lb	1.23	1.23	1.23
Non-California retail uncooked pork cuts	billion lb	10.67	10.66	10.66
Retail non-covered pork	billion lb	8.55	8.55	8.56
Producer and Consumer Surplus Changes				
Producer surplus change, Prop 12 converters	$ million	28.6	28.5	28.2

Producer surplus change, non-converters	\$ million	-52.2	-51.5	-50.7
Producer surplus change, total	\$ million	-23.6	-23.0	-22.5
Consumer surplus change, California	\$ million	-299.6	-298.2	-296.1
Consumer surplus change, non-California	\$ million	85.2	85.8	85.8
Consumer surplus change, total	\$ million	-214.4	-212.4	-210.3

Notes: cwt=hundredweight. Prop 12 requires that uncooked cuts of pork sold in California must come from compliant hogs. However, it does not cover other pork products, which denotes "non-covered pork" in this table. The term τ is the elasticity of transformation in the production of the two products (covered pork and non-covered pork). The base case is $\tau = 0.5$.

Appendix G. Detailed Description of Parameter Specification

This appendix provides detailed explanations on the methods for specifying the model parameter estimates that reflect California's Prop 12 regulations on pork sold in California and the North American pork supply chain.

Parameters of Primary Supply and Demand Functions

The parameters of primary supply and demand functions were calibrated around the 2018 values at the North American hog and pork markets. North America includes Canada and the United States. Exports and imports of pork products from the two countries were incorporated at 2018 values. The pork trade data came from related government agencies (USITC 2021; Government of Canada 2019). Consistent with prior work (Wohlgenant 1993; Saitone, Sexton, and Sumner 2015), the net trade quantity was assumed to be perfectly price inelastic.

In parameterizing the supply function of live hogs, the intercept and the slope of the supply function were calibrated such that the function fits the 2018 values for the hog production in North America (the United States and Canada) and has a price elasticity of supply given those values (specifically, 1.8). The supply elasticity value is consistent with a range of estimates suggested and used by previous papers studying the U.S. pork industry (Lemieux and Wohlgenant 1989; Wohlgenant 1993; Brester, March, and Atwood 2004; Saitone, Sexton, and Sumner 2015). This estimate reflects an intermediate-run horizon that allows the industry for a range of adjustments to buyers, or in this study, political jurisdictions, requiring the industry to adopt restrictive production practices.

To complete the calibration of the primary supply function, the farm price and the quantity of hogs were needed. The farm price came from the 2018 net farm value in "Meat Price

Spreads" reported by USDA ERS (2021b). The calculation started with the total number of hogs slaughtered in Canada and the United States, about 145 million hogs (Government of Canada 2021; USDA ERS 2021a). Converting the number of hogs to the retail weight generated 233 million pounds, based on the conversion factor, 160.8 pounds per hog, which the National Pork Board presented.

Parameterization of the retail demand functions used the fact that the aggregate demand for all pork is the horizontal sum of the two product demands. Suppose the direct demand function of aggregate pork in North America as

$$Q_{r,T} = a_T - b_T P_{r,T}, \tag{G.1}$$

$$Q_{r,T} = Q_{r,C} + Q_{r,N}, \tag{G.2}$$

$$P_{r,T} = \mu P_{r,C} + (1 - \mu) P_{r,N}. \tag{G.3}$$

A subscript T denotes total demand, and a subscript r denotes retail relationships. A subscript C denotes uncooked cuts of pork, and a subscript N denotes non-covered pork. The parameter μ is the share of covered pork in all pork. The variable, $P_{r,T}$, is the retail price of all pork, defined as a quantity weighted average of the two products that comprise all pork. As noted earlier, a linear function for the demand functions is used:

$$Q_{r,C} = a_c - b_{cc} P_{r,C} + h_{cn} P_{r,N}, \tag{G.4}$$

$$Q_{r,N} = a_n - b_{nn} P_{r,N} + h_{nc} P_{r,C}. \tag{G.5}$$

The relations from (G.1) to (G.5) imply the following relations:

$$h_{cn} = b_T \mu + b_{cc}, \tag{G.6}$$

$$h_{nc} = b_T (1 - \mu) + b_{nn}. \tag{G.7}$$

The two relations, (G.6) and (G.7), imply that the cross-price coefficients can be estimated given the own-price coefficients and the share of uncooked cuts of pork.

The own-price coefficients were estimated given the price elasticity of demand for all pork of -0.68 from Okrent and Alston (2011). This value compares closely to -0.69 and -0.79 used by Buhr (2005) and -0.65 reported by Wohlgenant and Haidacher (1989). Compared to the demand for all pork, the demands for the two sub-categories of pork products will be more price elastic because consumers are willing to substitute between the two categories in response to changes in their relative prices. A review of the relevant literature chose -0.9 for uncooked cuts of pork and -1.1 for non-covered pork in own-price elasticity.[20]

The calibration needs the retail prices and quantities of uncooked cuts of pork and non-covered pork. The retail revenue and quantity data by detailed categories of pork products were obtained from the National Pork Board. Based on the specification of uncooked cuts of pork defined by Prop 12, the quantities of small categories were aggregated into uncooked cuts of pork and non-covered pork. The corresponding retail prices were calculated by dividing the revenue by the quantity. The retail prices are \$3.30 per pound for uncooked cuts of pork and \$3.79 per pound for non-covered pork.

Parameters of Derived Supply and Demand Functions

Two sets of parameters characterize the derived supply and demand functions: (i) the processing and marketing costs of covered pork, c_C, and those of non-covered pork, c_N, and (ii) the parameters of the CET production possibility frontier, which are ρ, α, and A.

[20] Two studies are found to address demand for individual pork products and estimated the degree of consumer substitution among them in response to price changes. Nayga and Capps (1994) examined the demand for pork products based on data for a single retail store in Houston, Texas. Hailu et al. (2014) studied demand for pork products in Canada based on a panel of Canadian consumers. Both studies showed a modest willingness on consumers' parts to substitute among alternative pork products, but neither study's results were directly relevant to this research.

The parameter, c_C, came from the difference between the 2018 average retail price for uncooked cuts of pork and the 2018 average farm price for the retail weight of market hogs. A similar procedure was used to calibrate the processing and marketing cost of non-covered pork, c_N.

In terms of the parameters of the CET frontier, the first step was to assess the elasticity of transformation, τ, to be 0.5 for a long-run response. The next step was to obtain the value of ρ based on the relationship, $\tau = 1/(\rho - 1)$. The calibration of the other parameters, ρ, α, and A, is explained in Appendix E above.

Farm Costs of Compliance with California Regulations

To assess farm costs of compliance, three production cost data were used: (i) Hogs farrow-weanling production costs and returns, reported by USDA-ERS (2021), (ii) the farrow-to-wean budget constructed by AgManager.info, Department of Agricultural Economics, Kansas State University (Tonsor and Reid 2020), and (iii) the farrow-to-wean cost data reported by Iowa State University, Extension and Outreach (Christensen 2021).

The cost data above reflected typical stall housing operations. However, group housing has a cost advantage over the housing practice using gestation stalls to comply with the space requirement. According to the industry data, about 30% of North American sows were in group housing in 2020. However, about 8-9% of the North American hog production is needed for the California pork market. Hence, the hog production for the California market will come solely from the current group housing farms. Although group housing farms have a cost advantage, most of them do not meet California's standards. Hence, two steps were conducted: The first step was to compare the production costs between stall housing and typical group housing. The next step was to assess farm costs to convert typical group housing to California's standards housing.

The increase in capital recovery and related fixed costs: A common gestation stall allows about 14 square feet per sow (McGlone 2013). According to conversations with industry personnel, the typical group housing space allowance is about 20 square feet per sow of usable space on average. After the conversion from stall housing to group housing, the fixed costs must be spread over about 40% fewer sows, implying the fixed costs rise by about $4 per pig. The Prop 12 minimum space requirement is 24 square feet per sow of usable floor space. Hence, the fixed costs of Prop 12-compliant operations must be spread over 20% fewer sows than those using typical group housing, which results in incremental capital costs of about $3 per pig.

The increase in variable costs: Variable costs are higher in group housing than stall housing. In group housing where sows are mixed, sows compete for social dominance and feed, which causes increases in injuries and mortality and then negatively affects fertility (Supakorn et al. 2019). More veterinarian service is also likely to be needed in group housing. Furthermore, group housing negatively affects labor productivity. Individual stalls are helpful to trace and treat individual breeding pigs, which implies more labor is required in group housing than stall housing. Hence, converters could hardly reduce the total labor when fewer sows are confined in group housing than stall housing, implying an increase in the variable costs per pig. The incremental variable costs were assessed to be about $2 per pig based on the discussion above.

The conversion from typical group housing to California's standards also affects variable costs. The Prop 12 requirements are waived in the following cases: (i) five days prior to the expected farrowing date, (ii) nursing, and (iii) a maximum of six hours per day, not to exceed 24 hours in total over a 30-day period during breeding activities. Theses exemptions restrict typical practices during the breeding, farrowing, and weaning stages. Breeding pigs are often moved to farrowing crates earlier than five days prior to the expected birth date because of the condition of the breeding pigs. The period around mating is critical for sow reproduction, and prolonged stress can negatively affect sow reproduction during that period (Turner et al. 2005; Knox et al. 2014). Mixing breeding pigs immediately after weaning can cause higher levels of stress than mixing them after insemination (Rault et al. 2014). Individual caring for breeding pigs is often required because of the health condition of the breeding pigs, and the use of individual stalls is needed for this purpose. Group housing possibly needs more individual caring because of aggressive behaviors for social hierarchy and feed competition after mixing breeding pigs (Supakorn et al. 2019). Hence, more labor is needed in California's standards than group housing because Prop 12 requires more space allowance (24 square feet per sow) than typical group housing (20 square feet per sow). Based on the discussion above, the incremental variable costs were assessed to be about $2 per pig. Putting the incremental fixed and variable costs implies $5 per head as the total incremental costs for Prop 12 compliance.

The distribution of farm compliance costs: Consider how these costs are likely to vary across firms considering becoming Prop 12 compliant. Firms compete in the market for pork from sow farms using group housing. Therefore, those that remain in that market have comparable costs, with lower costs attributable to some firm-specific characteristic that differs across farms (perhaps managerial expertise for which the farm earns higher profits). Similarly, when firms compete in the market for Prop 12-compliant pork, some may have some unique attribute that allows them to earn higher profits than their peers in that market.

A uniform distribution was characterized for the 30% hogs, consistent with the share of current group housing operations in North America. About 70% of the hog production is under stall housing, and they were specified to supply non-compliant hogs. Given that slightly less than 10% of North American hogs are destined for California, farms covering roughly 20% of the total sows might seriously consider the option to produce Prop 12-compliant sows. One way to model the range of farms and the distribution of costs is to treat the calculated value ($5 per head) as roughly the midpoint of the uniform distribution of the first 20% hogs. If the range from $4 to $6 per head is taken for the first 20% hogs, this range is equivalent to a percentage increase in marginal cost per weanling pig increase of between about 10% and 14%. It is important to recognize that the operations with compliance costs in this range represent the low-cost end of potential Prop 12 cost for all hog farms. Given these conditions, the values are obtained for the lower bound and the upper bound of the distribution, $\underline{\sigma}$ and $\overline{\sigma}$, and the incremental variable costs, v, using the hundredweight basis ($\underline{\sigma} = \$2.49$ per cwt., $\overline{\sigma} = \$4.35$ per cwt., and $v = \$1.24$ per cwt.).

Additional Costs of Processing and Marketing Prop 12-Compliant Pork

Many primary processing operations or plants not to bother to acquire Prop 12 compliant hogs or market Prop 12 compliant uncooked cuts of pork, starting in 2022, accounting for only about 8-9% of hogs. These plants that choose not to supply the California market with compliant pork products will not have added costs of identifying, segregating, tracing, and labeling the compliant pork separately from the rest of their production.

Those primary processing operations that do acquire and process the more expensive compliant hogs will have additional costs to assure that they can sell this compliant pork into the California market. Pork destined for Prop 12-compliant products (and hence would require compliance) must be identified, segregated, and traced. Given the realities of modern processing, approximately 8-9% of compliant hogs will need to be segregated and processed in groups at different times from other hogs to assure that no non-compliant pork is intermingled with uncooked cuts of pork products destined for the California market.

If plants with about 42% of the total processing capacity in North America handled some compliant hogs, that would mean that, on average, they 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 scheduling would reduce the problems that hogs might spend several days too long in finishing operations or be 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 and only some plants accepting compliant hogs, and these costs must be accounted for in the price of compliant pork.

At the plant, the additional costs of processing include having separate holding pens, more complicated and less flexible, scheduling, interruption in plant operation between processing the compliant and non-compliant hogs, additional storage capacity so that approximately double the SKUs of fresh pork can be kept in distinct lots, a more complicated labeling process, and more complex shipping of labeled products. These added procedures have costs, but the costliest of these procedures is likely to be an 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 for the plant, equipment, and processing labor. Based on industry information and additional data, the best estimate in this research is that the additional cost is about $15 per compliant hog slaughtered.[21]

In addition to higher costs incurred at the primary processing plant, costs will be incurred for handling compliant pork throughout the downstream marketing chain. Based on conversations with secondary processors and marketers, these costs were estimated to be about $0.05 per compliant pork.

[21] For comparison see the segregation costs and implications in the context of Country of Origin Labeling as discussed in Sumner and Zuijdwijk (2019).

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