Modelling supply and demand in animal advocacy

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TODO: section on estimating the magnitudes of shocks? (Lusk et al., 2019)

TODO: replace all links within the text with citations?

TODO: start sections with a bullet point list of assumptions, applicability and limitations?

Example application of the approach in this doc: Chickens farmed for meat

Interventions and policies may affect prices, supply and/or demand for various animal products, therefore affecting the number of animals farmed or otherwise used for these products. It appears these effects haven't received much attention in the effective animal advocacy (EAA) space, including for animal welfare interventions. However, given how bad farmed animals' lives seem to be, I find it plausible that a change in the number of animals farmed is often more important than a change in average farmed animal welfare for an intervention aimed at improving welfare. Having more accurate estimates of these effects can allow us to pursue interventions that are more robust to ultimately subjective assumptions about average welfare with and without the intervention, like the welfare of caged vs cage-free egg-laying hens, or interventions whose major positive effects include reducing the number of animals farmed. Charity Entrepreneurship (CE) has been looking into subsidizing improvements in animal welfare, e.g. for farmed shrimps, and this can carry the risk of increasing the number of animals farmed if not handled carefully. CE has also looked into interventions targeting trade policy, for which we might expect effects on numbers of farmed animals to be quite important, and more work to estimate, given the complexity of international trade. For some discussion from the EAA space, see this post section by Animal Charity Evaluators on broiler campaigns, this blog post by Zach Freitas-Groff on a California ballot initiative on egg-laying hens, this report section on corporate campaigns for chickens by Saulius for Rethink Priorities, and an unpublished and preliminary investigation on cage-free eggs by Saulius for Rethink Priorities (contact Rethink Priorities to request access).

TODO: Should summarize and explain this paper; it's good and relevant example estimating the shock, modelling producers and profit maximization, and using an EDM
Lusk, J. L., Thompson, N. M., & Weimer, S. L. (2019). The Cost and Market Impacts of Slow-Growth Broilers. *Journal of Agricultural and Resource Economics*, *44*(3), 536-550.
https://ageconsearch.umn.edu/record/292330/
http://jaysonlusk.com/blog/2018/11/1/the-cost-and-market-impacts-of-slow-growth-broilers
https://docs.google.com/document/d/1obfgPdDEKk8I-EgNERPZgzCPkjuoA1SCTLCoTc2ZBo4/edit

"However, if one is committed to eating a given quantity of eggs, it is quite possible that the ethical thing to do is to eat eggs from the battery cage system. Why? Because it takes fewer hens to produce the same amount of eggs in a battery cage system than it does in a barn system (see the discussion in chapter 7 in Norwood and Lusk 2011a). If hens must suffer to produce eggs, it may be better to have fewer hens suffering more intensely than many hens suffering less intensely."

http://www.internationalegg.com/wp-content/uploads/2015/11/Lusk%20-%202011.pdf

I describe here different methods to estimate these effects, with increasing complexity, data requirements and accuracy. Upper bounds for the magnitudes of the effects can be estimated more easily than specifying full models and these bounds could be used for distributions or sensitivity analyses for cost-effectiveness analyses, or if the magnitude is small enough, the effect can be omitted entirely. More specifically, the bounds in 2, applicable whether international trade is important or not, are useful for checking whether the effects are significant at all and worth investigating further. After that, I expect section 3 to suffice for most problems not involving significant trade between regions, and if trade between regions is important, section 4, building on section 3, should be enough, although section 4 itself varies in complexity.

The document is organized as follows:

- Section 0 details how effects on numbers can be included and combined with welfare effects.
- Section 1 covers the basic microeconomic concepts and notation used throughout the document.
- Section 2 describes quick bounds for supply and demand effects. This is most appropriate when targeting the most harmful animal products or to show that the effects on numbers are insignificant, since these bounds are not very informative about effects on other animal products.
- Section 3 introduces equilibrium displacement models (EDMs) and applies them with elasticity estimates to simple uniform shocks. Replacement and substitution effects across different kinds of products are also captured.
- Section 4 describes how to model more complicated shocks with EDMs, including for trade between regions, as well as using the bounds from 2 for trade. Replacement effects across regions can also be captured here.
- Section 5 discusses other more complicated EDMs involving market power (monopoly, oligopoly, monopsony, oligopsony) and including more factors.
- Section 6 concludes the discussion of EDMs with limitations
- Section 7 discusses relevant existing research with econometric models, e.g. the impacts of California Proposition 2, which banned intensive confinement, on the number of farmed chickens, the impacts of media and information on meat demand.
- Section 8 lists large data sources and models from which EDMs and other models can be built.
- The appendix includes some useful calculus for EDMs.

You may also treat the parameters as random variables for Monte Carlo estimation: sample the parameters from the joint distribution, estimate the effects on that sample, and repeat for multiple samples and take the average effect, to approximate the expected value.
“Davis and Espinoza (1998, 2000), Griffiths and Zhao, and Zhao, et al.” Stochastic EDM, SEDM
https://www.researchgate.net/publication/23504384_CONFIRMATION_AND_FALSIFICATION_OF_EQUILIBRIUM_DISPLACEMENT_MODELS
(NAIS Benefit-Cost Research Team, 2009)

0. Including number effects in impact

Ideally, in cost-effectiveness analyses, effects on the numbers of animals should not be treated independently from welfare effects. If we are considering an intervention that would replace n_0 animal life-years at average welfare w_0 per life-year with n_1 animal life-years with average welfare w_1 per life-year (for some (sub)population), according to an additive (e.g. utilitarian) calculus, the net effect (for this (sub)population) is the difference

$$n_1 w_1 - n_0 w_0 \qquad (1)$$

and not, say, the sum of a welfare effect and a number effect, like

$$n_0 (w_1 - w_0) + (n_1 - n_0) w,$$

although the two expressions are actually equal with $w = w_1$ or when $n_1 = n_0$.

Expression (1) can be estimated for multiple non-overlapping affected (sub)populations of animals, and the expressions can all be added together. In other words, the net effect on welfare is the sum of effects over (sub)populations.

The interpretation of the parameters can be changed. Life-years can be replaced with life-days or other life-*time* units. Furthermore, n_0 and n_1 can be used as the total number of individuals, and w_0 and w_1 as the total welfare in a whole animal's life, averaged over the number of individual animals in each outcome. However, we should not calculate w_0 and w_1 by averaging welfare per year alive for an individual first, and then average over individuals (and multiply by average lifespan), since this will give greater weight to welfare per year in shorter lives.

Furthermore, the number of animals produced may differ from n_0 and n_1(due to early mortality, for example), and the quantity of product may not depend linearly on the number and vice versa, because of overall differences in productivity per animal or life-year, e.g. mortality, age at slaughter or sale, growth, final weight, milk or eggs produced, etc..

Given a quantity of product Q and r animal life-years per unit of product, which may depend on the scenario (with or without the intervention), we have $n = rQ$and can write the aggregate welfare as

$$nw = rQw$$

This can further be written as the aggregate per supplier of group of suppliers

$$nw = rQw = \sum_k r_k Q_k w_k = \sum_k n_k w_k ,$$

where w_k, n_k, r_k, Q_k are the corresponding values for average welfare, number of life-years, number of life-years per unit of product and quantity of product for each supplier or group of suppliers k. (This index $k$does not refer to with and without the intervention as above, where we had $k = 0, 1$. To distinguish them, we could use double subscripts like $n_{0,k}$, $n_{1,k}$, or superscripts or just different symbols for with and without the intervention, like m and n, u and w.)

TODO: p. 11/473 for EDMs here:
http://www.internationalegg.com/wp-content/uploads/2015/11/Lusk%20-%202011.pdf

1. Basics of microeconomics

Supply and demand. For a given product, like chicken meat, the *supply* (or *quantity supplied*) is the quantity of that product that is produced. The *demand* (or *quantity demanded*) is the quantity that is bought or would be bought with enough supply at the given price. Supply and demand depend on the price(s) of the product among other things, and so can be thought of as curves, or functions of these variables. Supply usually *increases* as the price of the product increases; producers want to sell more the more they can get for their products. On the other hand, demand usually decreases as the price of the product increases; buyers want to buy less the more it costs them to buy.

Market equilibrium. The actual quantity of a product sold in a market is where the supply and demand curves for that product in that market intersect, so supply and demand are equal at a given price, i.e. $S(p) = D(p)$(or $p_S(Q) = p_D(Q)$). This is the market clearing condition: of course, people can't buy more than is produced, but when the market clears, everything that is produced is also bought, and prices are just low enough so that this happens. This is the *equilibrium*. For multiple products and markets, for each product, the supply and demand curves intersect at the equilibrium.

TODO: graph of intersection/equilibrium of linear supply and demand curves

Supply and demand functions. Commonly used forms for supply and demand functions are linear and log-linear (or log-log, double log or constant elasticity), at least to a local approximation. Linear functions are characterized by a constant derivative, with a constant marginal change in quantity for the same difference(s) in price(s) as a function of price(s) and other variables, regardless of current price(s) and other variables, and log-linear models by constant elasticities, with the same marginal percent change in quantity for a given percent change in price regardless of the current price or quantity.

Typically, supply increases with price while demand decreases as price increases. If $S(p)$is the supply curve, giving quantity supplied for a product as a function of its price p (ignoring other dependencies for now), then its derivative is usually positive, $S'(p) > 0$, and $p' > p$ implies $S(p') > S(p)$. If $D(p)$is the demand curve, then its derivative is usually negative, $D'(p) < 0$, and $p' > p$implies $D(p') < D(p)$. Often the symbols $Q_S$and Q_D are used instead of S or D, respectively.

For a single market with a single product, we could assume the demand or supply curve is linear, like

$$Q(p) = ap + b,$$

or

$$p(Q) = cQ + d,$$

where $c = 1/a$ and $d =- b/a$. For supply, typically $a > 0,\ b < 0$, while for demand, $a < 0,\ b > 0$.

With multiple products, $i = 1, ..., n$,

$$Q_i(p_1, ..., p_n) = \sum_{j=1}^{n} a_{ij}\, p_{ij} + b_i,$$

and other independent variables like income (for demand), costs of inputs (for supply), time (for time trends) may be included, too.

In general, prices should be adjusted for inflation when multiple years are of interest. See (Norwood and Lusk, 2018, p. 189-190).

For ***log-linear models***, in the above equations, Q is replaced with $log\,Q$, and p with $log\,p$, so that a is exactly the price elasticity (see Elasticities below), and is therefore constant:

$$log(Q) \ = \ a\,log(p) \ + \ b, \text{ or}$$
$$Q \ = \ e^b p^a$$

TODO: short-run supply as the sum of inverse marginal cost curves, or profit-maximization.

Shock. A shock is a change in one variable (e.g. supply, demand, costs, price), *holding other variables fixed*. A shock will result in a new equilibrium quantity produced/consumed and a new price after unfixing the other variables, and for price/cost, supply and demand shocks, the change from the old equilibrium to the new will differ systematically from the shock itself. For example, a new tax will increase prices for consumers, but not by exactly the amount of the tax, since it also reduces supply and demand, and this change in quantity also has effects on prices. Or, if a disease leads to the culling of a large number of animals, as supply shock, we would expect supply to crease by less than this amount as other producers compensate. Sometimes this will happen through effects only on a small portion of a market, even at the level of individual producers.

Elasticities. The elasticity of a variable A with respect to another B (or B elasticity of A) is a measure of the *causal effect* of B on A, or the responsiveness of A to changes in B, in terms of percentage changes. The farther from 0 it is, the more elastic and responsive.

$\varepsilon_{AB} = \frac{\%\ change\ in\ A}{\%\ change\ in\ B} = \frac{\%\Delta A}{\%\Delta B} = \frac{\Delta A/A}{\Delta B/B} \approx \frac{dA}{dB}\frac{B}{A}$ for a small (percent) change in B, going to 0, holding any other variables affecting A fixed (in which case the derivative would be a partial derivative, and we'd use the notation $\frac{\partial A}{\partial B}$).

The price elasticity of supply or demand (often just referred to as the supply elasticity or demand elasticity) for product *i* is

$\varepsilon_i = \frac{\%\ change\ in\ Q_i}{\%\ change\ in\ p_i} \approx \frac{dQ_i}{dp_i}\frac{p_i}{Q_i}$.

In general, the (cross-)price elasticity of *i* with respect to the price of *j* is

$\varepsilon_{ij} = \frac{dQ_i}{dp_j}\frac{p_j}{Q_i}$

For the linear model above,

$\frac{dQ_i}{dp_j} = a_{ij}$, and so

$$\varepsilon_{ij} = \frac{dQ_i}{dp_j}\frac{p_j}{Q_i} = a_{ij}\frac{p_j}{Q_i}$$

For log-linear models, the coefficients are the elasticities and constant, and we may write

$$log(Q_i(p_1, ..., p_n)) = \sum_{j=1}^{n} \varepsilon_{ij} log(p_j) + b_i$$

Elasticities themselves may vary with price, income and product category (Lusk and Tonsor, 2016), so we should be careful about taking an elasticity estimate from one setting and applying it to another.

Short run vs long run. Our interventions are mainly targeted at the *long run*, but some effects are *short-run* effects. In the *short run*, the suppliers (firms) and some costs like capital are fixed, and the supply curve is the sum of supply curves over these suppliers, although suppliers can shut down and produce nothing if costs (including opportunity costs) exceed prices. In the *long run*, all costs are variable; suppliers may enter or leave the market, scale up or scale down by buying or selling capital, or hiring or firing employees. The exact period before the long run can depend on the industry.

For suppliers, the long run can involve building new housing and land change, which may take more than a year. Governments and industry groups often give farms several years to respond to new housing regulations, e.g. bans on cages or crates. The time to breed and raise new animals to productivity (slaughter for meat, or egg or dairy production) in response to increased demand can range on the order of months for chickens and a couple years for cattle. In (Brester et al., 2004), they use a 10-year period: “To simulate these cumulative effects, we assume it takes 10 years to adjust from the short run to the long run in the meat industry. A 10-year adjustment period was selected because beef cattle inventories have been characterized by 8-12 year cycles (Rosen, Murphy, and Scheinkman, 1994). Although hog cycles are of shorter duration and poultry cycles may be nonexistent, we use the beef industry average cycle length because of linkages among the meat sectors.”

For consumers, the long run can involve changing tastes or habits, larger purchases like cars or houses, among other things.

Supply and demand curves tend to be more elastic in the long run, and sometimes long-run supply is downward sloping for a decreasing cost industry, with the industry becoming more efficient with decreasing costs per unit of product as it scales. However, after accounting for potential confounders, supply elasticities should still be positive: an artificial price decrease for producers (e.g. a tax) should still decrease quantity supplied. Estimates of long-run elasticities and curves are harder to find.

If you can get suitable estimates of the long-run curves/elasticities and the impacts of an intervention are expected to last beyond the short-run, I recommend against relying entirely on short-term ones, instead choosing one of the following approaches:

1. Use only the long-run curves or elasticities over a period at least as long as that used to estimate the long-run elasticities.
2. Use short-run and long-run elasticities for the periods for which they were estimated, respectively, depending on the duration of the shock. A disease outbreak that leads to the culling of many animals

should normally be treated like a short-run shock, since these events are rare within a region, while new regulation should be treated like a long-run shock, since the effects tend to last for multiple years.

3. Allow the elasticity to start at the short-run (over the short-run period) and *multiplicatively* approach its long-run estimate up until the end of the estimate for the long-run is reached, after which it is just the long-run elasticity. This approach is taken in (Brester et al., 2004) and (NAIS Benefit-Cost Research Team, 2009). The latter also had priors on the elasticities and both used Monte Carlo simulations to estimate consumer and producer surplus change. **TODO**: Letting ε_{SR}, ε_{LR} be the short-run and long-run elasticities, respectively, t_0, t_{SR}, t_{LR} be the time of the initial shock, the duration of the short-run period for the short-run elasticity estimate and the duration of the long-run period for the long-run elasticity estimate, we would define
    a. $\varepsilon(t) = \varepsilon_{SR},\ t \le t_0 + t_{SR}$
    b. $\varepsilon(t) = \left(\frac{\varepsilon_{LR}}{\varepsilon_{SR}}\right)^{\frac{t-t_0-t_{SR}}{t_{LR}-t_{SR}}} \varepsilon_{SR},\ t_0 + t_{SR} \le t \le t + t_{LR}$
    c. $\varepsilon(t) = \varepsilon_{LR},\ t \ge t_0 + t_{LR}$

    This can be extended to elasticity estimates for more than 2 periods, and we could even have the elasticities start at 0 at t_0 and increase to ε_{SR} at $t_0 + t_{SR}$.
4. Check both the long run and short run and do a sensitivity analysis.

There is also research on impulse responses in economics, although this seems primarily of interest in macroeconomics. https://en.wikipedia.org/wiki/Impulse_response#Economics

In (Norwood and Lusk, 2018, p. 194), given a short-run curve for quantity that depends on the quantity of the same product in a previous period(/s), e.g. $Q(p, Q_{-1}, \ldots)$, setting $Q(p, Q_{-1}, \ldots) = Q_{-1}$(and setting all quantities of the same product equal) and solving for Q_{-1} in terms of p (and any other variables) gives the long-run curve. If the current quantity does not depend significantly on past quantities after including other variables, then *the short-run and long-run curves are the same*.

References on short run vs long run:
https://www.lesswrong.com/posts/gjie7bsCT2gaHHQqp/misapplied-economics-and-overwrought-estimates
https://www.economicshelp.org/blog/glossary/short-run-long-run-very-long-run/
https://www.khanacademy.org/economics-finance-domain/microeconomics/elasticity-tutorial/price-elasticity-tutorial/a/elasticity-in-the-long-run-and-short-run
https://en.wikipedia.org/wiki/Cost_curve
Section 2.5.5 in https://rune.une.edu.au/1959.11/10827

2. Bounds from supply or demand shocks

Section summary: a supply or demand shock itself can be used as the maximum change in quantity resulting from the shock, as a bound. These bounds also apply in cases with international trade, as discussed in section 4.1. This is most appropriate when targeting the most harmful animal products or to show that the effects on numbers are insignificant, since these bounds are not very informative about effects on other animal products. Not all shocks are supply or demand shocks, though, and other kinds are discussed in the next sections.

In this section, we consider only a single product and ignore effects on other products, although we might expect a decrease in quantity in one animal product to be compensated for by at most an equal increase in quantity in other animal products (in total), allowing us to derive bounds for other products. Keep in mind that the net effect can still be negative if the substituted animal products are more harmful, of the same kind or of a different kind, e.g. substituting chicken for beef or lower welfare chicken for higher welfare chicken. See the small animal replacement problem. For estimating welfare effects, these bounds are most useful for animal products with the worst average welfare or most suffering by weight, or per calorie, or per gram of protein. In section 3 and after, this assumption can be relaxed to consider substitution effects more explicitly, accurately and flexibly, where a decrease in consumption of one product is partially compensated for with the increase in another, or vice versa.

Given a shock in the quantity suppliers would produce at the same price, i.e. a change in quantity holding other factors constant, the change in quantity produced to reach the new equilibrium price should usually be smaller in absolute, i.e. closer to 0, regardless of whether the change was an increase or a decrease. In other words, the shock overestimates the actual effect and the new equilibrium quantity should be *between* the original and the original quantity + the shock. This is assuming, as is typical, that the quantity demanded decreases or remains constant with increasing prices, and the quantity supplied increases or remains constant with increasing prices.

TODO: picture

The same is true for a demand shock: the actual change in quantity to the new equilibrium should be smaller, and the new equilibrium quantity should be closer to the original.

TODO: picture

Therefore, letting

- Q_0= original equilibrium quantity,
- Q' = new quantity that would be supplied (or demanded) at the same original equilibrium price, and
- Q_1 = actual quantity at the new equilibrium,

then

$$|Q_1 - Q_0| \leq |Q' - Q_0|$$

and the quantities in the absolute values have the same sign. Put another way:

- If $Q' > Q_0$, then $0 \leq Q_1 - Q_0 \leq Q' - Q_0$.
- If $Q' < Q_0$, then $0 \geq Q_1 - Q_0 \geq Q' - Q_0$.

This can then be used to bound a probability distribution for the quantity of product at the new equilibrium, or to bound the range for the new quantity produced in a sensitivity analysis.

TODO: In a few studies, US poultry supply was treated as very elastic, using supply elasticities of 10-14, so the demand shock itself would actually be a good approximation of the change in quantity.
https://onlinelibrary.wiley.com/doi/full/10.1111/cjag.12215

3. Equilibrium displacement models (EDMs)

With estimates of baseline quantities, prices and elasticities, usually taken from other studies, and an estimate of the shock, whether in the quantity, price or other factors, we can build and solve an *equilibrium displacement model* (EDM), and do much better than the bounds in section 2. EDMs are locally linear approximations of the supply and demand curves, or more specifically, the *changes* to these curves and the market equilibrium, hence the name *equilibrium displacement* model. Since the approximation is local, we should not expect EDMs to be accurate except for relatively small shocks, and their accuracy will of course also depend on the accuracy of the models. Usually, markets are assumed to be perfectly competitive for EDMs, at least approximately, although see section 5 on relaxing this condition. Economists primarily use EDMs for *ex ante* analysis, i.e. estimating the effects of some event before the event occurs and data is observed. When this data is available, *ex post* analysis with econometric models using this data is usually preferred for greater accuracy, although it's also more work (Davis and Espinoza, 1998), (Davis, 2001); some specific applications of such models are discussed briefly in section 7.

I illustrate with a simple EDM in 3.1. To handle trade between regions, see section 4, which builds on section 3.

For another overview of EDMs, see (Wohlgenant, 2011).

TODO: another review:
https://www.researchgate.net/publication/23945881_Research_Benefits_in_a_Multimarket_Setting_A_Review

TODO: p. 11/473 for animal welfare effects here:
http://www.internationalegg.com/wp-content/uploads/2015/11/Lusk%20-%202011.pdf

3.1. Parallel supply and demand shocks

In this section, I describe an EDM for a percentage shock in supply or demand (assuming a fixed price and holding all else equal, too), which tracks the percentage change in quantity and price given such a shock. For example, short-run supply may decrease due to an infectious disease killing many farmed animals. Based on Chapter 3 from (Norwood and Lusk, 2018),

$\%\Delta D$= the percentage change in quantity demanded from the original equilibrium to the new equilibrium
$\%\Delta S$= the percentage change in quantity supplied from the original equilibrium to the new equilibrium
$\%\Delta p$= the percentage change in price from the original to the new equilibrium

ε_D = price elasticity of demand

ε_S = price elasticity of supply

Q_0 = original equilibrium quantity (assumed equal for supply and demand)

K_D = percent change in demand due to an exogenous shock (holding price and other factors constant)

= exogenous demand change / original quantity = $\frac{Q' - Q_0}{Q_0}$

K_S= percent change in supply due to an exogenous shock (holding price and other factors constant)

= exogenous supply change / original quantity = $\frac{Q' - Q_0}{Q_0}$

Then, with this notation, we have the following equations for the equilibrium displacement model which approximate the effects of (small) *parallel* (additive) shifts of size $K_D Q_0$ and $K_S Q_0$ on demand and supply curves, respectively:

$$\%\Delta D = \varepsilon_D * \%\Delta p + K_D$$
$$\%\Delta S = \varepsilon_S * \%\Delta p + K_S$$

Setting $\%\Delta D = \%\Delta S = \%\Delta Q$ for the new equilibrium, we have

$$\%\Delta p = (K_D - K_S)/(\varepsilon_S - \varepsilon_D)$$
$$\%\Delta Q = (K_S - K_D)/(1 - \varepsilon_S/\varepsilon_D) + K_D = (K_D - K_S)/(1 - \varepsilon_D/\varepsilon_S) + K_S$$

So the actual change in quantity to the new equilibrium is

$$\%\Delta Q * Q_0,$$

and the new equilibrium quantity is

$$Q_0 + \%\Delta Q * Q_0 = (1 + \%\Delta Q) * Q_0.$$

Aside on the cumulative elasticity factor

$\frac{1}{1-\varepsilon_D/\varepsilon_S} = \frac{\varepsilon_S}{\varepsilon_S - \varepsilon_D}$ is the *cumulative elasticity factor*, and is less than 1, under the usual assumptions $\varepsilon_S > 0, \varepsilon_D < 0$. If one person decides or multiple people decide to purchase $q(= K_D Q_0)$ fewer units of a product, the actual quantity produced should decrease by roughly $\frac{\varepsilon_S}{\varepsilon_S - \varepsilon_D} q < q$ units in *expectation*. The cumulative elasticity factors are > 0.5 for many common animal according to estimates in https://www.amazon.com/Compassion-Pound-Economics-Animal-Welfare/dp/0199551162, https://reducing-suffering.org/comments-on-compassion-by-the-pound/#Elasticities
, but these may vary. For other discussion of cumulative elasticities in the EA community, see
http://www.animalcharityevaluators.org/wp-content/uploads/2013/12/cef.pdf
https://forum.effectivealtruism.org/posts/fZp6Fpowmd5a8Lu2w/what-is-the-current-best-estimate-of-the-cumulative

Holding the demand elasticity fixed and letting the supply elasticity approach infinity for perfectly elastic supply, the cumulative elasticity factor approaches 1, and the demand shock K_S becomes the actual change, matching the approach in section 2. The same happens if we let the demand elasticity approach 0 for perfectly inelastic demand, holding the supply elasticity fixed. We can do the same, switching the roles of supply and demand (although supply is rarely close to perfectly inelastic).

Multiple products and cross-price elasticities

These equations can easily be adjusted to include cross-price elasticities or income elasticities just by adding the relevant terms and additional similar equations for other products.

For income elasticities, we could add $\varepsilon_{DI} * \%\Delta I$ to the equation for $\%\Delta D$, where $\varepsilon_{DI}$is the income elasticity of demand and $\%\Delta I$is the percent change in income.

With 2 products (including possibly only slightly differentiated products, e.g. free-range eggs and caged eggs), using subscripts 1 and 2, and cross-price elasticities, we could solve the following system of equations:

$$\begin{aligned}
\%\Delta D_1 &= \varepsilon_{D1} * \%\Delta p_1 + \varepsilon_{D12} * \%\Delta p_2 + K_{D1} \\
\%\Delta S_1 &= \varepsilon_{S1} * \%\Delta p_1 + \varepsilon_{S12} * \%\Delta p_2 + K_{S1} \\
\%\Delta D_2 &= \varepsilon_{D2} * \%\Delta p_2 + \varepsilon_{D21} * \%\Delta p_1 + K_{D2} \\
\%\Delta S_2 &= \varepsilon_{S2} * \%\Delta p_2 + \varepsilon_{S21} * \%\Delta p_1 + K_{S2}
\end{aligned}$$

For each product, there will be 2 unknowns, for (percent change in) quantity and price; and 2 equations, for (percent change in) demand and supply. For n products, this is a system of 2n linear equations with 2n unknowns. Setting $\%\Delta D_i = \%\Delta S_i$ for each product i, and collecting

- the elasticities into n x n matrices for supply and demand, E_S and E_D
- the percentage price changes into a n-length vector, $\%\Delta p$, and
- the shocks into n-length vectors for supply and demand, K_S and K_D,

the system of equations in matrix-vector form becomes =

$$E_D \%\Delta p + K_D = E_S \%\Delta p + K_S ,$$

and rearranging,

$$(E_S - E_D) \%\Delta p = K_D - K_S.$$

Row reduction, Cramer's rule or inverting the matrix $E_S - E_D$ and multiplying both sides by the inverse can be used to solve the system.
WolframAlpha can be a convenient way to solve these equations if there are a small number of them.

For examples, see Chapter 3 in (Norwood and Lusk, 2018), or
https://socialsci.libretexts.org/Bookshelves/Economics/Book%3A_An_Interactive_Text_for_Food_and_Agricultural_Marketing_(Thomsen)/04%3A_Market_Equilibrium_and_Equilibrium_Modeling/4.03%3A_Section_3-
https://socialsci.libretexts.org/Bookshelves/Economics/Book%3A_An_Interactive_Text_for_Food_and_Agricultural_Marketing_(Thomsen)/04%3A_Market_Equilibrium_and_Equilibrium_Modeling/4.05%3A_Section_5-

3.2. Building EDMs

EDMs are based on finite approximations of total derivatives, and understanding them, differentiation rules and partial derivatives is helpful for building more complicated EDMs. The total derivative of a function is the best locally linear approximation of that function, when the changes to the inputs approach 0. We define the supply and demand curves (possibly aggregated across regions), take their total *log* derivatives, i.e. total derivatives of their natural logarithms (noting that $d\,log(x) = d\,ln(x) = \frac{dx}{x}$, since $\frac{\partial ln(x)}{\partial x} = \frac{1}{x}$) with respect to non-constant quantities, set these total log derivatives equal to impose the market clearing/equilibrium condition, and replace the differential terms, like dx, with the corresponding finite changes, like Δx. This is a first-order linear approximation. We can derive the above simple single market system as follows. First, we define supply and demand curves as functions of prices and a variable that may be subject to a shock:

1. $S(p, k_S)$: Supply quantity as a function of price and another variable
2. $D(p, k_D)$: Demand quantity as a function of price and another variable

Next, we take the total log derivatives of supply (demand is similar):

$$dln(S(p, k_S)) = \frac{dS(p,k_S)}{S(p,k_S)} = \frac{1}{S(p,k_S)}\left(\frac{\partial}{\partial p}S(p, k_S)\,dp + \frac{\partial}{\partial k_S}S(p, k_S)\,dk_S\right) = \frac{p}{S(p,k_S)}\frac{\partial}{\partial p}S(p, k_S)\,\frac{dp}{p} + \frac{\partial}{\partial k_S}S(p, k_S)\,\frac{dk_S}{S(p,k_S)}$$

And $\varepsilon_S = \frac{p}{S(p,k_S)}\frac{\partial}{\partial p}S(p, k_S)$ is the price elasticity of supply, so

$$\frac{dS(p,k_S)}{S(p,k_S)} = \varepsilon_S\frac{dp}{p} + \frac{\partial}{\partial k_S}S(p, k_S)\,\frac{dk_S}{S(p,k_S)}$$

Notice that we haven't used any assumptions about the shock yet, other than that it's a single variable, and yet the form of the equation is the same as the one from the last section. That is, after

1. replacing the differentials (d-terms) with the finite differences (Δ-terms), and
2. defining $K_S = \frac{\partial}{\partial k_S}S(p, k_S)\,\frac{\Delta k_S}{S(p,k_S)}$,

we get

$$\frac{\Delta S}{S} = \varepsilon_S * \frac{\Delta p}{p} + K_S$$

which is the same as

$$\%\Delta S = \varepsilon_S * \%\Delta p + K_S$$

So, supply and demand shocks are very general: all other shocks *become* supply or demand shocks in an EDM, and specifically, parallel shifts, when the initial price p and initial value of k_S are used to compute

$$K_S = \frac{\partial}{\partial k_S}S(p, k_S)\,\frac{\Delta k_S}{S(p,k_S)}.$$

When the supply shock is a parallel shift, we may define $S(p, k_S) = S(p, 0) + k_S$, so that $\frac{\partial}{\partial k_S}S(p, k_S) = 1$, so $K_S = \frac{\Delta k_S}{S(p,k_S)}$ and $\frac{dS(p,k_S)}{S(p,k_S)} = \varepsilon_S\frac{dp}{p} + \frac{dk_S}{S(p,k_S)}$.

The same works for demand, so we recover the equations in 3.1 by setting the total log derivatives of the two functions equal. When there are more variables, possibly multiple subject to shocks at the same time, e.g. supply is a function $S(p,\ x_1,\ ...,\ x_n)$, then

$\%\Delta S\ =\ \varepsilon_S\ *\ \%\Delta p\ +\ \sum_{i=1}^{n} \varepsilon_{Si} * \%\Delta x_i$, where $\varepsilon_{Si} = \frac{x_i}{S(p, x_1, ..., x_n)} \frac{\partial}{\partial x_i} S(p,\ x_1,\ ...\ x_n)$

and defining $K_S = \sum_{i=1}^{n} \varepsilon_{Si} * \%\Delta x_i$, it is again the same as a supply shock.

We can also generalize to multiple products the same way as in section 3.1.

See the Appendix for some useful identities for total (log) derivatives.

TODO: proportional/pivotal shocks?

3.3. Uniform price and cost shocks

Price and cost shocks are exogenous changes in the prices or costs for suppliers or consumers, this time holding quantities and all else constant, before a new equilibrium is reached. Many price and cost shocks can be modelled as simple shifts of the supply or demand curve, by increasing or decreasing the price for each unit of product *uniformly* regardless of quantity, i.e. a *parallel shift*. Such a parallel shift occurs, for example, when the introduction of a *per unit* (specific) tax or a change in an input cost alters the price by a fixed amount. On the other hand, percentage (*ad valorem*) taxes/tariffs result in a *uniform* rescaling or multiplication of the supply or demand curve (or its price argument) by a constant factor, i.e. a *proportional shift*. For a single market with a single product, whether for a parallel shift or a proportional shift, it doesn't matter which of the supply or demand curve is shifted. For example, a new or higher tax decreases prices from the point of view of suppliers, but increases prices from the point of view of consumers; suppliers would receive less per unit and consumers would spend more per unit.

Consider a change in tax or subsidy or cost *per unit* of $K*\ p_0$for suppliers, where p_0 is the initial equilibrium price. For the supplier, we have $K\ <\ 0$ for an increase in cost or taxes or a decrease in subsidy, $K\ >\ 0$ and for a decrease in cost or taxes or an increase in subsidy. Then, we could model this with the following EDM:

$$\%\Delta D\ =\ \varepsilon_D\ *\ \%\Delta p$$
$$\%\Delta S\ =\ \varepsilon_S\ *\ (\%\Delta p\ +\ K)$$

Note that this is exactly the system from section 3.1 if we set $S_D\ =\ 0$ and $S_S = \varepsilon_S\ *\ K$. Solving this system gives $\%\Delta p\ = \frac{\varepsilon_S * K}{\varepsilon_D - \varepsilon_S} = \frac{K}{\frac{\varepsilon_D}{\varepsilon_S} - 1}$, and $\%\Delta Q\ = \frac{\varepsilon_D * \varepsilon_S}{\varepsilon_D - \varepsilon_S} K$. Note that since, typically, $\varepsilon_D\ <\ 0\ <\ \varepsilon_S$, this means $\%\Delta Q$ will have the same sign as K, so a cost reduction ($K\ >\ 0$) increases the quantity, as expected.

We could also instead solve the following system and get $\%\Delta Q = \frac{\varepsilon_D * \varepsilon_S}{\varepsilon_D - \varepsilon_S} K$here, too:

$$\%\Delta D = \varepsilon_D * (\%\Delta p - K)$$
$$\%\Delta S = \varepsilon_S * \%\Delta p$$

For a percentage tax or subsidy of $100k\%$, this time applied to the demand side first, we would get $k > 0$ for a tax increase or subsidy decrease, and $k < 0$ for a tax decrease or subsidy increase. We can then build the EDM by writing the demand function as $D(p, k) = D_0((1 + k)p)$ and taking total log derivatives:

$$\%\Delta D = \varepsilon_D * ((1 + k)\%\Delta p + k)$$
$$\%\Delta S = \varepsilon_S * \%\Delta p$$

Solving this system gives $\%\Delta p = \frac{-\varepsilon_S * k}{(1+k)\varepsilon_D - \varepsilon_S}$and $\%\Delta Q = \frac{-\varepsilon_D * \varepsilon_S * k}{(1+k)\varepsilon_D - \varepsilon_S}$, whose sign will be opposite of k's, so, a tax increase reduces the quantity.

3.4. Parallel vs proportional shifts and linear vs log-linear models

Shocks are usually modelled as parallel shifts, and for small shifts, the quantity and price solutions to the EDM equations in 3.1, which are (locally) linear approximations, have at most small errors regardless of the functional forms of the supply and demand curves, and are exact assuming the model is linear locally. If a shock is a proportional (multiplicative) shift, (locally) log-log models have similar accuracy guarantees; proportional shifts of $Q(p)$ correspond to parallel shifts of $log\ Q$ as a function of $log\ p$. See sections 2.5.1, 2.5.2 and 3 in (Zhao et al., 2000). In (Alston et al., 1995), they argue for parallel shifts with a linear approximation as the default, at least for productivity growth.[1] However, in (Takeshima, 2009), they argue for log-linear (constant elasticity) models and pivotal shifts, and compare both approaches.[2] (Wohlgenant, 2011) concludes "From my

[1] **TODO** "The industry curve is based on the aggregation of supply curves for individual firms. Shifts in the industry curve depend on the effects of new technologies on the marginal costs of existing firms and on entry and exit of firms. One would need to examine the characteristics of individual firms that affect marginal costs and technology adoption in order to predict which types of firms would benefit from a particular new technology. In addition, with current techniques and typically available data, it is not possible to settle these questions econometrically. We might hope to obtain plausible estimates of elasticities at the data means, but definitive results concerning functional forms are unlikely and it is impossible to get statistical results that can be extrapolated to the price or quantity axes (i.e., the full length of the function) with any confidence. Thus, assumptions about the nature of the research-induced supply shift are unavoidable. Our conclusion is that it is important to be aware of the consequences of different assumptions. Our preference - in the absence of the information required to choose a particular type of shift - is to follow Rose's (1980) suggestion and employ a parallel shift. Rose (1980, p. 837) argued that "For most innovations, the best information available may be a cost-reduction estimate for a single point on the supply curve .... [It] is unlikely that any knowledge of the shape of the supply curve, or the position at which the single estimate applies, will be available. The only realistic strategy is to assume that the supply shift is parallel." We find the arguments of Rose persuasive, and therefore we are inclined to assume vertically parallel research-induced supply shifts. Under this assumption, the functional forms of supply and demand are unimportant and it is convenient to use a local linear approximation as suggested by Alston and Wohlgenant (1990)."

[2] **TODO** "Formula (4) assumes linear supply curves, with productivity growth expressed as a parallel shift in the supply curve. Using (4) when the supply elasticity is less than 1 is controversial. Any linear supply curve with

perspective, a major limitation of the EDM framework is that it is strictly only valid for small changes. If large changes are considered, then one is implicitly assuming either linear functional forms or constant elasticity functional forms. More work along the lines of Zhao, Mullen, and Griffith (1997) in characterizing the magnitude of errors in the EDM framework is desirable. Even when it is not possible to overcome the problems of dependency on functional form, it would be wise to perform sensitivity analysis by developing results for both linear and constant-elasticity functional forms."

TODO:
https://www.researchgate.net/publication/23945881_Research_Benefits_in_a_Multimarket_Setting_A_Review
https://ageconsearch.umn.edu/record/12462/?ln=en

TODO: 3.5 Multi-level models

Wohlgenant, 2011
https://ageconsearch.umn.edu/record/292330/

4. The importance of disaggregation

Market shocks can affect subsets of the market in different ways, and it can be important to analyze the effects across subsets. Substitution effects across different types of animal products can be important and even harmful overall, e.g. if consumers replace beef with chicken. This can even happen with the same kind of animal product. Suppose we improve farm animal welfare at a cost for suppliers with already higher than average welfare, within its region or across regions with trade between them. This may reduce supply from those higher welfare suppliers, and lower welfare suppliers may increase their supply to compensate. The intervention could do more harm than good, and without decomposing supply across farm types and checking the effects for each, we might not find this out! This kind of (short-term) backfire effect seems less likely if we focus on animals who are worst off and used in the greatest quantity for the same amount of food.

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elasticity less than 1 measured at the initial equilibrium has zero MC for up to some positive production quantity. Voon and Edwards (1991) also prefer to use the constant elasticity form with pivotal shifts, because it provides more conservative estimates of benefits than the linear form when supply elasticity is less than 1, as is the case of this study. AEDM assumes a supply curve in constant elasticity form, which avoids the problem of zero MC for positive production quantity. AEDM uses a pivotal shift to express productivity growth for several reasons. First, a pivotal shift in a constant elasticity supply curve assumes a proportional reduction in MC at each production quantity. For biological or yield-increasing productivity growth that does not require additional input, such as GM cassava, a proportional reduction in marginal cost may be realistic, because for each unit of output, a farmer reduces the input by the same proportion (Lindner and Jarrett 1978; Rose 1980).
Second, for computation purposes, when we assume different farmgate price levels, assuming the same reduction in MC for all producers is questionable. Moreover, it is not feasible to do so in simulation, because the reduction in MC can be greater than the initial level of MC for some producers who have relatively low MC at the initial equilibrium production level." (Takeshima, 2009)

So, we see that the changes to supply curves may be more complicated than simple uniform parallel or proportional shifts. This is particularly true when the adoption of different technologies is involved and in the long run, since the effects on each firm may depend on their characteristics (e.g. farm size) and producers may enter or exit the market. (Wohlgenant, 1997) The rough consensus seems to be that for changes in technology -- and I would argue by extension, production methods and costs --, rather than apply uniform shifts, markets should be disaggregated by firm characteristics (including adoption and non-adoption) and shifts applied to each group. I think a parallel cost/price shift is defended most in particular; see (Alston, Norton and Pardey, 1995), (Davis et al., 2014) and footnote 1, although see also footnote 2, which argues for pivotal shifts. However, even this approach may be an invalid approximation for the long run, since it doesn't appropriately account for entry and exit. For example, all firms could have linear supply curves, and so a sum over a fixed set of them (and therefore the short-run curve) would be linear, but the long-run supply curve could fail to be linear due to the entry of new firms (Wohlgenant, 1997).

Suppliers have been grouped in terms of broad characteristics like farm size or technology adoption, and the group supply curves have been estimated as the sum of inverse marginal cost curves (Hayami and Herdt, 1977), (Qaim, 1998), (Wohlgenant, 2005), (Takeshima, 2009). In principle, some such groupings would allow entry into and exit from each group, e.g. new large farms starting or small farms shutting down. We might fix the suppliers, especially if we want to derive the supply curve from marginal cost curves, or we might at least fix the individual suppliers in the market targeted by an intervention, e.g. subsidization or a corporate campaign. However, fixing all the suppliers in a group (possibly the entire market, with 1 group) would assume no entry into or exit from that group. This assumption is fine for the short run, but may be unrealistic and make for an inaccurate approximation for the long run. So, we should avoid fixing suppliers as much as possible, and keep this source of model error in mind.

Suppose there are n supplier groups (possibly some with exactly 1 supplier, or if we fix all suppliers, this could be n suppliers) producing the same undifferentiated product, labelled $1, .., n$, and group i is subject to a shock parametrized by k_i, representing their supply function by $S_i(\overline{x_i}, k_i)$, where $\overline{x_i}$ is a vector with all the non-shock variables (the endogenous variables, e.g. prices). Then we write the aggregate supply for this product as the sum:

$$S = S(\overline{x_1}, ..., \overline{x_n}, k_1, ..., k_n) = \sum_{i=1}^{n} S_i(\overline{x_i}, k_i)$$

The total log derivative of this is the quantity-weighted average of total log derivatives:

$$dln(S) = \frac{dS}{S} = \frac{1}{S}\sum_{i=1}^{n} dS_i = \frac{1}{S}\sum_{i=1}^{n} S_i dln(S_i)$$

and we'd use the baseline quantities for S and the S_i in the finite approximation.

For parallel shifts, usually $k_i = 0$ would recover the original supply function, so that

1. $S_i(\overline{x_i}, k_i) = S_i(\overline{x_i}, 0) + k_i Q_{i0}$ for a quantity shock increasing quantity by k_i times the baseline quantity or decreasing it by $-k_i$ times the baseline quantity, or

2. $S_i(\overline{x_{i,}}, k_i) = S_i(\overline{x_{i,}} + k_i, 0) = S_{i0}(\overline{x_{i,}} + k_i)$ for a cost shock decreasing cost by k_i or increasing it by $-k_i$.

We've already seen what $dln(S_i) = \frac{dS_i}{S_i}$ should look like for these cases in the previous sections:

1. $dln(S_i) = \frac{dS_i}{S_i} = \varepsilon_i \frac{dp}{p} + k_i +...$ for the quantity shock, if k_i is the relative shock, and $k_i Q_{i0}$ is the absolute shock.
2. $dln(S_i) = \frac{dS_i}{S_i} = \varepsilon_i \left(\frac{dp}{p} + k_i\right) +... = \varepsilon_i \frac{dp}{p} + \varepsilon_i k_i +...$ for the cost shock.

The ellipses are intended to capture any other non-constant variables, of which there may be none.

In both cases, we would get

$dln(S) = \frac{dS}{S} = \frac{1}{S}\sum_{i=1}^{n} dS_i = \frac{1}{S}\sum_{i=1}^{n} S_i dln(S_i) = \sum_{i=1}^{n} \frac{S_i}{S}\varepsilon_i \frac{dp}{p} + \sum_{i=1}^{n} \frac{S_i}{S} K_i +...$, where $K_i = k_i$ or $\varepsilon_i k_i$, for the quantity and cost shocks, respectively.

And from this we can see that the price elasticity of the aggregate supply is the weighted average of price elasticities, $\sum_{i=1}^{n} \frac{S_i}{S}\varepsilon_i$.

Then, when we solve for the new equilibrium in the aggregate model, $\frac{dS}{S} = \frac{dD}{D}$, we will get the relative change in equilibrium price, $\frac{dp}{p}$, and we can get the relative change in supply in each group i as $\frac{dS_i}{S_i} = \varepsilon_i \frac{dp}{p} + z_i$ where z_i is the part of the shock specific to group i, if any.

In the long run, consumers or suppliers may enter or leave the market. If the cost per product increases for a subset of suppliers, these suppliers may be more likely to leave the market and possibly be replaced by new suppliers. On the other hand, if the cost per product decreases for a subset of suppliers, they may outcompete other suppliers and push them out of the market. A price increase for particular consumers or a price decrease for particular producers may push them to exit the market.

Furthermore, if the costs of specific inputs per unit of product change, it is not necessarily the case that suppliers' costs will change by the same amount, since suppliers can change their inputs to reduce costs. So a cost increase assuming inputs don't change overestimates the actual cost increase and hence overestimates the decrease in supply, but assuming costs are absorbed gives us a bound on the change. On the other hand, a cost decrease assuming inputs don't change doesn't go far enough, since producers may find a better mix of inputs, and the new equilibrium quantity should be *greater* than just shifting the curve by the decrease would give.

4.1. Trade between regions

When there are multiple regions and no trade barriers between them, equilibrium displacement models can be used. We can simply sum the supply curve expressions for a given commodity into an aggregate supply curve expression, and similarly for demand, and then set these two aggregate changes equal as we just saw at the start of section 4. However, with government-imposed trade barriers like ***tariffs*** (taxes on imports or exports) or ***quotas*** (limits on imports or exports) and even natural trade barriers like transportation costs, it may be inaccurate to aggregate the supply curves or demand curves across regions and treat this like a single market. Trade barriers between regions reduce total quantities and increase average prices of products. Despite this, according to (Sumner, 2006), if these trade barriers are held constant, then we can use equilibrium displacement models as approximations, with the weighted averages of supply elasticities and weighted averages of demand elasticities over (sub)regions as the elasticities, like just described. Governments may adjust trade barriers in response, and we could try to capture that possibility with EDMs, too. For example, by advocating for mandatory certification of certain products or country-of-origin labelling in one country, other countries might retaliate by increasing trade barriers.

As a first approximation without elasticities, for supply and demand shocks, we can use the same bounds from 2: the quantities should shift in the same direction as the shock, and the magnitude of the shock is an upper bound for the displacement of the equilibrium quantity.

As a second more accurate approximation, we can use elasticities and build an EDM as in (Sumner, 2006). (Sumner, 2006) in particular uses two regions, one for the United States, and another for the rest of the world, and estimates the effects of subsidies. The price elasticity of the aggregate supply curves across regions in the rest of the world is the weighted average of supply elasticities, weighted by the share of supply in each region, like in the previous section, and the demand curve and demand elasticities are constructed the same way. However, these aggregated elasticities don't account for trade barriers, which partially insulate production and consumption from world trade prices, and so the "real" elasticities should be closer to 0 (Sumner, 2006). Since trade barriers may be specific to pairs of countries, this approximation may be inaccurate for tracking changes in production or consumption by region, rather than in total.

TODO: For more conservative bounds, it may be worth using supply and/or demand elasticities that are greater or smaller in absolute value, depending on the kind of shock. For a supply quantity shock, if we take a more extreme demand elasticity estimate (across regions) and a less extreme supply elasticity estimate as the global demand and supply elasticities, consumers would absorb more of the shock and the change in actual quantity at equilibrium would be closer to the shock. If we take the *most extreme* demand elasticity estimate and the *least extreme* supply elasticity estimate, the change in equilibrium for this frictionless closed world economy model should give us a rough bound on the actual change; the actual change should be closer to 0 than this. For a demand quantity shock, use a more extreme supply elasticity estimate and a less extreme demand elasticity estimate.

TODO: There might also be asymmetric effects, where an increase in supply or demand has more resistance against it than a decrease, due to quotas and other trade barriers, although a decrease in one region may be partially compensated for by an increase in another. The aggregate supply and demand curves may be better approximations for decreases than for increases.

Trade policies and barriers can also be included more explicitly in EDMs, especially if they are *not* constant and we want to consider their impacts; see (Lee and Sumner, 2006) as an example for how this can be done, allowing for changes in tariffs and quotas on trade, as well as in domestic subsidies. They even allow for country-specific quotas, e.g. an import quota imposed by Korea on the US. Quotas can be *binding* or *non-binding*: a ***binding quota*** is a quota set low enough that the equilibrium would be different without it, while a ***non-binding quota*** is set too high to make a difference. (Lee and Sumner, 2006) assume that whether a quota is binding or not is not affected by the shock, i.e. binding quotas remain binding and non-binding quotas remain non-binding, which is probably reasonable for small shocks. However, it's worth checking that no quotas are passed at the new equilibrium. They also assume net importers remain net importers and net exporters remain net exporters, which is also probably reasonable for small shocks. Furthermore, they include input factors in their model: labor, material input, and land.

With EDMs, I'm not aware of a way to handle cost-like trade barriers specific to pairs of countries, like transportation costs or a tariff imposed by one country specifically on another.

TODO: tariffs
https://www.tandfonline.com/doi/abs/10.1080/00036840500217523

Products can also be differentiated by country or region of origin, essentially treating otherwise identical products as distinct, or recognizing systematic differences in product characteristics by origin. This is done with separate demand curves (and elasticities, and cross-price elasticities) for domestic products vs imports, like *import demand models*, possibly multiple demand curves for import demand for different countries of origin. In a country, demand for imports from other countries and supply of exports to other countries tend to be relatively elastic (Alston and James, 2002). (Lusk and Anderson, 2004) estimate the effects of country-of-origin labelling on meats in an EDM including domestic and foreign meats, and as such use separate demand functions for domestic and foreign products. (Kinnucan and Myrland, 2005) estimate the effects of income growth and tariffs on the world salmon market with an EDM, with export supply elasticities and import demand elasticities for each country, but aggregating all imports to a given country together instead of separating by country of origin. Import and export elasticities are harder to find in the literature and may often not exist at all.

Finally, as an even more complex and accurate approximation, we can estimate the equilibrium in different scenarios directly using *spatial equilibrium models*. These involve many more parameters for trade barriers between each pair of regions (including pairwise tariffs, quotas and transportation costs), and typically require linear programming (or more complicated) solvers. (Kalaitzandonakes et al., 2014) and (Peterson and Orden, 2002) describe and illustrate how to build these models and solve for their equilibria both at baseline and in hypothetical scenarios. Spatial equilibrium models can be validated at baseline; (Kalaitzandonakes et al., 2014) found their model to be fairly accurate for quantity supplied and demanded in most countries at baseline. WATSIM is a large spatial equilibrium model covering the world in aggregated regions, "29 commodities (...) crops, livestock products, and processed food", with cross-price elasticities, income trends, demand trends and yield trends. By aggregating regions, WATSIM sacrifices some accuracy for practical feasibility.

Spatial equilibrium models predict that trade of a given product between two countries can only go in one direction, i.e. net importers of a product do not export any of it, and net exporters of a product do not import any of it, so to the extent that this is not the case, differentiating the products by origin may improve the accuracy of the model and the accuracy of the disaggregated changes.

5. Other variables and imperfect competition for EDMs

On the demand side, quantity demanded varies with income, so it may be worth including income growth projections as done in (Kinnucan and Myrland, 2005), for example. It is not always the case that quantity demanded increases with supply; a product may be inferior, an ***inferior good***, because more expensive products are preferable when consumers can afford them. Media, information and advertisements may also affect demand, as discussed in section 7.

On the supply side, producers' inputs (labour, materials, land, other capital) and their prices may not be fixed and can themselves be modeled as subject to supply and demand. For example, consumers buy chicken meat from retail stores, which buy it from farms. See section 3 in (Wohlgenant, 2011).

Usually, markets are assumed to be perfectly competitive, at least approximately, so that any individual seller or buyer is too insignificant to affect market prices, i.e. they have no market power. (Alston et al., 1997) allow for imperfect competition and market power in their EDMs for estimating the impacts of research, capturing both oligopoly power (at the extreme, monopoly power), i.e. market power for sellers; and oligopsony power (at the extreme, monopsony power), i.e. market power for buyers (including firms buying inputs). They also check both parallel and pivotal shifts. They found that modest departures from perfect competition affected the distribution of benefits between producers, but did not affect the total much, while large departures affected both significantly. (Harrington and Dubman, 2008) use quadratic programming instead of traditional EDMs (more like spatial equilibrium models in the last section) to address some limitations of EDMs, mostly related to the assumption that shocks must be small, and also handle imperfect competition.

TODO: is there a consensus around how to treat market power? A lot of work by Sexton.

https://www.researchgate.net/publication/46556895_A_Flexible_Oligopoly-Oligopsony_Model_for_Classroom_Simulations_and_Policy_Analyses

"players set quantity simultaneously and precludes Stackelberg or dominant firm behavior" but generalizes Cournot competition.
https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1574-0862.2009.00428.x

Testing (im)perfect competition
With EDMs: http://wp.demm.unimi.it/tl_files/wp/2013/DEMM-2013_01wp.pdf
Lloyd T, McCorriston S, Morgan W et al. (2006). Food scares, market power and price transmission: the UK BSE crisis. Eur Rev Agric Econ 33: 119-147.
Lloyd T, McCorriston S, Morgan W et al. (2006). Market power in UK food retailing: theory and evidence from seven product groups, contrib paper prepared for the 24th IAAE Conference, Gold Coast, Australia 2006.
Lloyd T, McCorriston S, Morgan W et al. (2009) Buyer power in UK food retailing: a 'first-pass' test. J Agr Food Ind Organ Vol 7, Article 5.
Gardner B L (1975) The farm-retail price spread in a competitive food industry, Am J Agr Econ, 76: 641-646.

6. TODO: Other Extensions of and Alternatives to EDMs, EDM validation

“Assumptions of Equilibrium Displacement Models
As noted by Piggott et al. (1995), equilibrium displacement models rest on four key assumptions:
1. Elasticities of endogenous supply and demand relationships are known and constant.
2. Elasticities of supplies and demands, with respect to exogenous variables, are known and constant.
3. Technology of production is known and constant.
4. Displacements are restricted to be in the neighborhood of equilibrium.

Limitations of Equilibrium Displacement Models
Those assumptions are also the Achilles heel of equilibrium displacement models:
1. Adjustment scenarios often entail changing any or all of the above assumptions, analyzing large displacement from the initial equilibrium, and/or determining base equilibrium values from indirect data, thus complicating their application.
2. Expansionary displacements assume that no physical constraints to expansion exist, for example, no limitations on total cropland or limitations on existing production capacity.
3. Some contractionary displacements can exceed 100 percent of the base level of the activity. Such solutions are a priori infeasible because they imply the process in question is operating in reverse.
4. Equilibrium displacement model supply functions are assumed to be downwardly continuous, whereas a correct specification requires that each supply function be truncated at the point where its supply price drops below its average variable cost.
5. Neither expansionary nor contractionary displacements can be guaranteed to be on the efficient frontier of the underlying production/demand functions, but may be either interior points or infeasible points.
6. In the constant elasticity equilibrium displacement formulation, it is not conceptually possible to calculate a correct monopolistic/monopsonistic maximum quasi-rent solution. Quasi-rents change monotonically upward or downward, with successive restrictions in output, depending on whether demand is inelastic or elastic.

To overcome these limitations, we adopt an MP implementation of the equilibrium displacement model.”
(Harrington and Dubman, 2008)

“To clarify the ideas put here, consider the relationship between a structural modelling approach (whole-farm LP or simulation) and a supply–demand equilibrium displacement approach. Even in situations where demand is inelastic, the structural modelling approach is the best way to estimate the position and form of the supply curve and the nature and extent of any shift in it. It is substantially better in practice than making simplistic assumptions about supply elasticities, functional forms and supply shifts, as is common in the equilibrium displacement approach. However, to adequately account for the inelasticity of demand, the supply curve(s) estimated using the structural model should be employed in a standard equilibrium displacement approach to estimate changes in producer and consumer surpluses. In cases where demand is sufficiently elastic so that consumer surplus can reasonably be disregarded, the structural modelling approach is theoretically equivalent to the equilibrium displacement approach. The change in profit (or perhaps certainty equivalent) estimated using the structural model is the theoretically correct measure of producer benefits, and there is no need to repeat the exercise in an equilibrium displacement analysis which, if it does anything, is likely to distort the estimated benefit by imposing restrictions on the functional form of supply or the nature of the supply shift.”

https://www.sciencedirect.com/science/article/pii/S0308521X99000426?casa_token=ItqJ-XVDdg4AAAAA:vgJz_3VZU3ylbB-hp49vplL_TdfQ0fSKmpg6FUDGjtpzt2xmKr75BI9Oqu2ePWKFrVUIj2SlVg

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.226.6052&rep=rep1&type=pdf
AEDMs, log-linear models
(Takeshima, 2009)

TODO: EDM validation

Proposes procedures to validate (stochastic) EDMs.
https://www.researchgate.net/publication/23504384_CONFIRMATION_AND_FALSIFICATION_OF_EQUILIBRIUM_DISPLACEMENT_MODELS

https://ninum.uit.no/handle/10037/17446
https://ninum.uit.no/bitstream/handle/10037/17446/article.pdf?sequence=2&isAllowed=y

https://onlinelibrary.wiley.com/doi/full/10.1111/cjag.12215

https://ageconsearch.umn.edu/record/301062/?ln=en

https://www.researchgate.net/publication/227463286_The_Logic_of_Testing_Structural_Change_in_Meat_Demand_A_Methodological_Analysis_and_Appraisal

https://www.researchgate.net/profile/Garry_Griffith/publication/23519524_The_Relative_Payoffs_From_RD_and_Generic_Advertising_Expenditure_by_the_Australian_Pig_Industry/links/53fbffe30cf2dca8fffee6f8.pdf

7. Empirical analysis with econometric models

With enough data of the right kind and certain model assumptions, we can forecast supply and demand, estimate the impacts of interventions or other shocks after the fact, and estimate supply and demand curves. This section discusses research with these techniques that's been done that I think is already informative for effective animal advocacy. For discussion of the different kinds of models used, Chapter 7 of (Norwood and Lusk, 2018) provides a brief introduction and Part IV of (Tomek and Kaiser, 2014) provides more in-depth coverage.

Keep in mind that it isn't enough to just run a simple linear regression of quantity on price or vice versa to estimate a supply or demand model. Absent assumptions about shifts of one of the curves, the expected slope of a simple linear regression of quantity on price or vice versa will be an average of the slopes of the supply and demand curves, assuming they're linear, (Hansen, 2020, p. 339), and it doesn't tell us about the slopes of each curve separately, so this is not useful for estimating how the equilibrium would change in response to a shock to either supply or demand. To estimate the supply curve, we would want to hold it constant (or include independent variables for its changes) while demand undergoes a shock, and vice versa for demand.

Unexplained demand shifts in fish
https://academic.oup.com/erae/article/45/4/531/4934746
https://munin.uit.no/handle/10037/6539

Proposition 2, cage ban:
http://www.zachgroff.com/2017/11/animal-welfare-reforms-are-looking.html
http://jaysonlusk.com/blog/2020/6/3/california-animal-welfare-laws-impacts-egg-prices-nationwide
https://faunalytics.org/californias-standards-for-confining-farm-animals-initiative/
https://onlinelibrary.wiley.com/doi/abs/10.1111/ajae.12104?campaign=wolearlyview
https://www.researchgate.net/publication/46556611_The_Effect_of_Proposition_2_on_the_Demand_for_Eggs_in_California
https://onlinelibrary.wiley.com/doi/abs/10.1093/ajae/aax049
https://ageconsearch.umn.edu/record/246252/?ln=en
https://www.jstor.org/stable/23243064

https://ageconsearch.umn.edu/record/169051/

Corporate cage-free campaigns
https://thehumaneleague.org/article/E008R02-relationship-commitments-production

Trends in vegetarianism
https://onlinelibrary.wiley.com/doi/abs/10.1093/ajae/aaw110

Some econometric demand models have been designed with economic theory, like budget constraints, in mind. Two popular models are Rotterdam models and Almost Ideal Demand Systems. For discussions and empirical comparisons of these models, see (Alston and Chalfrant, 1993), (Barnett and Seck, 2008), (Sherafatmand and Baghestany, 2015). (Tonsor and Olynk, 2011) used Rotterdam demand models to estimate the effects of animal welfare articles in top US publications on demand for meat. I've summarized and interpreted the results: in 2008, based on their paper, at the margin and if we can interpret the results causally, each article published on chicken welfare may have spared 300,000 chickens from being farmed, although there are many caveats and qualifications for this estimate.
https://forum.effectivealtruism.org/posts/rHpqQ66aqt3xc6Y5W/summary-impacts-of-animal-well-being-and-welfare-media-on

"Contesting ballot initiatives has also been shown to have negative market repercussions, as it increases public attention on perceived farm animal welfare issues [**19**,**22**]. More recently, disputes over "ag gag" laws—that seek to limit the ability of opponents to take undercover videos and pictures—have led some to infer that animal agriculture has something to hide. Because negative media affects the entire industry, there is reason for programs that maintain social trust."
https://www.mdpi.com/2076-2615/9/6/367

"We find that advertising in support of Proposition 2 was more effective in raising subjects' willingness-to-pay for cage-free eggs than ads in opposition were in reducing it, but we also find that ads in support of the

measure reduce the dispersion of preferences and thus polarize attitudes toward the initiative. More generally, political ads are found to contain considerably more "hype" than "real information""
https://asu.pure.elsevier.com/en/publications/media-advertising-and-ballot-initiatives-the-case-of-animal-welfa
https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1465-7287.2011.00292.x

"We can also say, based on past empirical evidence, that it is extremely difficult to demonstrate any positive demand response to domestic advertising of pig meat."
"based on past empirical evidence, it is extremely difficult to demonstrate any positive demand response to domestic advertising in the Australian pork market. All previous studies using Australian data (Piggott et al. 1996, Zhang and Goddard 1999) and all but one study using North American data (Brester and Schroeder 1995, Duffy and Goddard 1995) have estimated generic pork advertising elasticities not significantly different from zero. In such a case there would no benefit from advertising and producers would incur a loss equal to the amount of the advertising expenditure. Mounter et al. (2004b) showed that the Australian elasticity of demand response to generic pork advertising would have to exceed 0.035 for pig producers to gain from a generic advertising program for domestic pork, funded by a lump sum. This value is toward the upper end of any previously estimated values for the demand response to generic advertising. See also Freebairn, Goddard and Griffith (2005) for a more general treatment of the conditions under which generic advertising is likely to be cost effective to producers."
https://www.researchgate.net/publication/23519524_The_Relative_Payoffs_From_RD_and_Generic_Advertising_Expenditure_by_the_Australian_Pig_Industry

TODO: However, maybe this is due to too small sample sizes. What about willingness-to-pay studies?
https://forum.effectivealtruism.org/posts/jSPGFxLmzJTYSZTK3/reality-is-often-underpowered

There have also been multiple studies on the effects of information, media and advertisements about health and food safety on meat demand using Rotterdam models and Almost Ideal Demand Systems. For a few, see

https://www.jstor.org/stable/1243939

https://www.sciencedirect.com/science/article/abs/pii/S0169515001000925

https://www.jstor.org/stable/3697881

https://onlinelibrary.wiley.com/doi/abs/10.1002/agr.10033

https://www.tandfonline.com/doi/abs/10.1080/000368496328434

"The data used in this application are from the US broiler chicken market."

https://ninum.uit.no/handle/10037/17446

“The aim of our study is to develop a comparative forecasting approach and determine the best forecasting methods and models for each type of red meat (i.e. goat, seep, buffalo carcass, and cattle and calf carcass). Accordingly, we used ARIMA, exponential smoothing and STLF forecasting methods. Quarterly data between 2010 and 2018 published by Turkish Statistical Institute were used. The results of the study showed that comparing more than one forecasting method rather than using a single method in estimating the amount of red meat production will produce more reliable and accurate results.”
https://dergipark.org.tr/en/pub/lahaed/issue/56364/719095

8. Data and estimated models

TODO: Should actually just try to get access to these models?

USDA:
- Includes data from multiple countries, not just the US, although primarily US and China
- No longer updated
- https://www.ers.usda.gov/data-products/commodity-and-food-elasticities/
- https://data.ers.usda.gov/reports.aspx?ID=17825

WATSIM:
- Spatial world trade model with elasticities and cross-price elasticities
- Includes Wheat, Barley, Maize, Other cereals, Rice, Starch crops, Sugar, Pulses, Soya seed, Sunflower seed, Rapeseed, Other oilcrops, Soya oil, Sunflower oil, Rape oil, Other oil, Beef, Pigmeat, Other meat, Poultry, Eggs, Milk, Cheese, Butter/cream, Skim milk powder
- https://www.ilr.uni-bonn.de/agpo/rsrch/watsim/wats_pub_e.htm

FAPRI:
- https://www.fapri.missouri.edu/publication/documentation-of-the-fapri-modeling-system/
- https://www.fapri.missouri.edu/wp-content/uploads/2015/03/FAPRI-MU-Report-12-04.pdf
- https://www.fapri.missouri.edu/about-fapri/history/

CAPRI:
- https://www.capri-model.org/dokuwiki/doku.php?id=start

Implan
- https://www.implan.com/

OECD-FAO Agricultural Outlook
https://www.agri-outlook.org

CERES:

- https://ceresproject.eu/
- https://www.frontiersin.org/articles/10.3389/fmars.2020.568159/full, https://www.frontiersin.org/articles/10.3389/fmars.2021.578516/full

World Bank + IFPRI:
- https://documents.worldbank.org/en/publication/documents-reports/documentdetail/458631468152376668/fish-to-2030-prospects-for-fisheries-and-aquaculture

FAOSTAT

WTO

Eurostat

PS&D

FAS (Foreign Agricultural Trade)

The ERS CGE model uses data from the Global Trade Analysis Project (GTAP database, version 7.2). The GTAP database includes 57 commodities and 101 country/regions.
https://pdfs.semanticscholar.org/abb4/79acf5f593ca2241cc33c737069a6c63bbf5.pdf

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References

Alston, J. M., & Chalfant, J. A. (1993). The silence of the lambdas: A test of the almost ideal and Rotterdam models. *American Journal of Agricultural Economics*, *75*(2), 304-313.
https://www.researchgate.net/publication/255582086_The_Silence_of_the_Lambdas_A_Test_of_the_Almost_Ideal_and_Rotterdam_Models

Alston, J.M., G.W. Norton and Pardey, P.G. (1995), Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting, Cornell University Press, Ithaca and London.

Alston, J. M., & James, J. S. (2002). The incidence of agricultural policy. Handbook of agricultural economics, 2, 1689-1749.
https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=1012&context=agb_fac

Alston, J. M., Sexton, R. J., & Zhang, M. (1997). The effects of imperfect competition on the size and distribution of research benefits. *American Journal of Agricultural Economics*, *79*(4), 1252-1265.
https://www.jstor.org/stable/1244282

Barnett, W. A., & Seck, O. (2008). Rotterdam model versus almost ideal demand system: will the best specification please stand up?. *Journal of Applied Econometrics*, *23*(6), 795-824.
http://www2.ku.edu/~kuwpaper/2006Papers/200605.pdf

Brester, G. W., Marsh, J. M., & Atwood, J. A. (2004). Distributional impacts of country-of-origin labeling in the US meat industry. *Journal of Agricultural and Resource Economics*, 206-227.
https://www.jstor.org/stable/40987216?seq=1

Davis, G. C., & Espinoza, M. C. (1998). A unified approach to sensitivity analysis in equilibrium displacement models. *American Journal of Agricultural Economics*, *80*(4), 868-879.
https://www.jstor.org/stable/1244070

Davis, G. C. (2001). *Confirmation and Falsification of Equilibrium Displacement Models* (No. 374-2016-19852).
https://www.researchgate.net/publication/23504384_CONFIRMATION_AND_FALSIFICATION_OF_EQUILIBRIUM_DISPLACEMENT_MODELS

Davis, J., Bantilan, M. C. S., Nedumaran, S., & Kumara Charyulu, D. (2014). The importance of disaggregation for understanding research impacts and modelling adoption.
http://oar.icrisat.org/7821/

Djunaidi, H. (2005). *Is the US Losing its Competitiveness in the Global Chicken Markets: A Spatial Equilibrium Analysis*. Available at SSRN 779327.
https://papers.ssrn.com/sol3/papers.cfm?abstract_id=779327

Hansen, B. E.. (2020). *Econometrics*.
https://www.ssc.wisc.edu/~bhansen/econometrics/Econometrics.pdf

Harrington, D. H., & Dubman, R. (2008). *Equilibrium Displacement Mathematical Programming Models: Methodology and Model of the US Agricultural Sector* (No. 1488-2016-124228).
https://www.ers.usda.gov/webdocs/publications/47526/16783_tb1918c.pdf?v=0
https://www.ers.usda.gov/webdocs/publications/47526/12867_tb1918.pdf?v=41056

Hayami, Y., & Herdt, R. W. (1977). Market price effects of technological change on income distribution in semisubsistence agriculture. *American Journal of Agricultural Economics*, *59*(2), 245-256.
https://www.jstor.org/stable/pdf/1240014.pdf

Kalaitzandonakes, N., Kaufman, J., & Miller, D. (2014). Potential economic impacts of zero thresholds for unapproved GMOs: The EU case. *Food Policy*, *45*, 146-157.
https://www.sciencedirect.com/science/article/abs/pii/S0306919213000791

Kinnucan, H. W., & Myrland, Ø. (2005). Effects of income growth and tariffs on the world salmon market. *Applied economics*, *37*(17), 1967-1978.
https://www.tandfonline.com/doi/abs/10.1080/00036840500217523?src=recsys&journalCode=raec20

Lee, H., & Sumner, D. A. (2006). *Effects of the WTO and Free Trade Agreements on Japonica Rice Markets* (No. 1004-2016-78719).
https://core.ac.uk/download/pdf/6653386.pdf

Lusk, J. L., & Anderson, J. D. (2004). Effects of country-of-origin labeling on meat producers and consumers. *Journal of Agricultural and Resource Economics*, 185-205.
https://core.ac.uk/download/pdf/7060252.pdf

Lusk, J. L., & Tonsor, G. T. (2016). How meat demand elasticities vary with price, income, and product category. *Applied Economic Perspectives and Policy*, *38*(4), 673-711.
https://onlinelibrary.wiley.com/doi/abs/10.1093/aepp/ppv050

NAIS Benefit-Cost Research Team. (2009). Benefit-cost analysis of the national animal identification system.
https://www.agmanager.info/sites/default/files/BC_Analysis_NAIS.pdf

Norwood, F. B., & Lusk, J. L. (2018). *Agricultural marketing and price analysis*. Waveland Press.

Peterson, E. B., & Orden, D. (2002). *Effects of Tariffs and Technical Barriers on High-and Low-Value Poultry Trade* (No. 375-2016-20018).
https://ageconsearch.umn.edu/record/19658/

Qaim, M. (1998). Transgenic virus resistant potatoes in Mexico: Potential socioeconomic implications of north-south biotechnology transfer. *ISAAA Briefs*, *7*, 1-48.
https://www.isaaa.org/Resources/publications/briefs/07/download/isaaa-brief-07-1998.pdf

Sherafatmand, H., & Baghestany, A. A. (2015). Comparison of Rotterdam Model versus almost ideal demand system for fish and red meat. *Agrekon*, *54*(1), 120-137.
https://www.tandfonline.com/doi/abs/10.1080/03031853.2015.1019522

Sumner, D. (2006). Effects of US upland cotton subsidies on upland cotton prices and quantities. *Annex I to First Written Submission of Brazil to the Panel in the United States Subsidies on Upland Cotton (DS 267) Recourse by Brazil to Article*, *21*.
https://aic.ucdavis.edu/research1/Sumner_WTO_Cotton.pdf

Takeshima, H. (2009). Sensitivity of welfare effects estimated by equilibrium displacement model (No. 00936). Discussion Paper.
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.226.6052&rep=rep1&type=pdf

Tomek, W. G., & Kaiser, H. M. (2014). *Agricultural product prices*. Cornell University Press.

Tonsor, G. T., & Olynk, N. J. (2011). Impacts of animal well-being and welfare media on meat demand. *Journal of Agricultural Economics*, *62*(1), 59-72. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1477-9552.2010.00266.x

Wohlgenant, M. K. (1997). The nature of the research-induced supply shift. *Australian Journal of Agricultural and Resource Economics*, *41*(3), 385-400. https://onlinelibrary.wiley.com/doi/pdf/10.1111/1467-8489.t01-1-00019

Wohlgenant, M. K. (2005). Market Modeling of the Effects of Adoption of New Swine Waste Management Technologies in North Carolina. *Unpublished, North Carolina State University*. https://projects.ncsu.edu/cals/waste_mgt/smithfield_projects/phase2report05/cd,web%20files/B2.pdf

Wohlgenant, M. K. (2011). Consumer demand and welfare in equilibrium displacement models. *The oxford handbook of the economics of food consumption and policy*, 0-44. https://www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780199569441.001.0001/oxfordhb-9780199569441-e-12

Zhao, X., Griffiths, B., Griffith, G., & Mullen, J. (2000). The economic impacts of new technologies and promotions on the Australian beef industry. https://rune.une.edu.au/1959.11/10827

Appendix

Calculus for EDMs

TODO: chain rule

Total derivative identities

1. $df(x, y, ...) = \partial f/\partial x * dx + \partial f/\partial y * dy + ...$, or $df(x_1, x_2, ..., x_n) = \sum_{i=1}^{n} \partial f/\partial x_i * dx_i$
2. $d(f \times g) = gdf + fdg$

Total log derivative identities

1. $dln(f(x, y, ...)) = df/f = (\partial f/\partial x * dx + \partial f/\partial y * dy + ...)/f = \partial f/\partial x * x/f * dlnx + \partial f/\partial y * y/f * dlny +$

    a. $\partial f / \partial x * x / f$ is the x elasticity of f!
2. $dln(f) = (\partial ln(f) / \partial f) df = df / f$, so $df = f dln(f)$
3. $dln(f \times g) = dln(f) + dln(g)$, so if f or g is constant, it can be ignored
4. $dln(f + g) = \frac{f}{f+g} dln(f) + \frac{g}{f+g} dln(g)$
    a. $dln(\sum_{i=1}^{n} f_i) = \frac{1}{\sum_{i=1}^{n} f_i} \sum_{i=1}^{n} f dln(f)$
    b. In approximations for EDMs, I've seen the baseline values for f, g, f_i used.
5. Quotas, as maximum limits on quantities imported or exported, may be non-differentiable. If we're already hitting the quotas, then we can't go past them. Many countries don't have agreements to trade a given commodity at all, so their quotas are effectively 0, so we can't be away from these quotas. **TODO**: Does throwing them all into a rest-of-world market make sense anymore?
    - $dln(max(f, C) = dlnf$if $f < C$, undefined at equality (depends on the sign of the change) and 0 otherwise.