The Impact of Information on Input Market Pricing: Evidence from a Bull Market

PRELIMINARY DRAFT: DO NOT CITE OR CIRCULATE

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Abstract

I use a hedonic model to estimate the impact of introducing new product characteristics into an agricultural input market in the United States. To guide producers toward more sustainable cattle, both governments and breed associations suggest releasing new genetic traits on environmental sustainability to help dairy farmers identify cattle that are more environmentally efficient. To understand how dairy farmers have reacted to new traits being added to the market for cattle genetics, I use the prices and characteristics of over 24,000 dairy bulls sold between 2000 and 2010 to estimate the impact of adding new health traits on cattle pricing. In the case of one health trait measuring fertility, the trait initially factored negatively into cattle prices but eventually became positive. My results suggest that understanding the correlations between cattle characteristics is key to understanding how new characteristics will impact cattle pricing and the demand for other, similar traits.

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1 Introduction

Innovation in products occurs not only by improving existing characteristics but also creating new characteristics. Improvements in cell phones, for example, have been characterized by not only improving existing features like memory and battery life but also expanding its features (e.g. camera, internet access) (Crawford and Neary, 2023). Expanding the scope of characteristics is also important for firms in agriculture which use genetics inputs. Research into animal and plants and genetics not only improves the traits of the available genetics but also expands the range of outcomes that can be measured.

How do firms respond to the introduction of new characteristics into their input markets? Answering this question is important for understanding how effective publishing new characteristics will be for changing the input decisions of firms. I examine the case of the dairy genetics market, in which dairy bull semen is sold to dairy farmers to create new replacement dairy cows for their farms. Each bull has a variety of calculated genetic traits which are estimated by the USDA. For example, one of the most important dairy bull traits is milk yield which is calculated using milk yield data from its offspring. As more and more traits are able to be measured, dairy bulls acquire more traits. Understanding the impact of these new traits on cattle pricing is especially important since animal scientists and policymakers have recently suggested measuring methane emissions and releasing this as a genetic trait in the market. If the USDA were to release these traits to dairy farmers, how might they react?

To shed light on this question, I examine the prices and genetic traits of 24,000 dairy bulls sold between 2000 and 2010 to understand how firms, in this case dairy farmers, incorporated new traits into their decisions by examining how characteristics capitalize into a bull's price over time. During this period, the USDA introduced three new health traits and incorporated them into a selection index, a weighted average of genetic traits meant to reflect their importance for a certain breeding goal (Hazel, 1943). The USDA's selection index, called "Net Merit," weights traits based on the amount of profit expected from increasing that trait in the offspring by one unit. While in 2000 the index was 61% dedicated to production, the USDA introduced three traits measuring fertility and birthing health that reduced Net Merit's focus on production to 46% and increased the focus on health traits from 23% to 40%.

To determine whether dairy farmers adopted these health traits, I use a hedonic model with two different approaches. In the first approach, I take advantage of the fact that the coefficients of a hedonic regression reflect the perceived profitability of different traits and can be directly compared to the profitability weights of the Net Merit index. I estimate a hedonic regression in three periods where Net Merit weights were updated to factor in new health traits and use these coefficients to produce an alternative "Hedonic Net Merit" index. I compare the hedonic index to the Net Merit weights in each period of revisions to determine whether shifts in Net Merit toward health traits are followed by shifts in the pricing of dairy bulls. In the second approach, I apply a "difference-in-difference" style approach using the fact that new health traits, once they are released, are calculated retroactively for bulls that have already passed away. This allows me to examine the impact of health traits on the price before and after they were introduced into the market.

I specifically examine the case of the fertility trait, which is economically important to farmers but could not be directly selected on before its introduction. Theoretically, the impact of a new characteristic on pricing depends on i) the extent to which firms were unable to select on this characteristic before it was released to the market and ii) the economic importance of the trait. Since fertility outcomes are observed by dairy farmers, they are incentivized to do so even without a trait directly measuring it. If they can select on the trait using other traits with sufficient precision, the impact of introducing a measure of that trait should be minimal. Similarly, the impact of new trait information will be small if producers do not believe the trait is economically significant. If other "proxy" genetic traits were previously used by dairy farmers to select fertility, we should expect a decrease in demand for proxy traits and an increase in demand for fertility through its measured importance to price.

At baseline, I find evidence that dairy producers value genetic traits very differently than Net Merit. Physical traits make up less than 20% of Net Merit but are nearly 50% of the index made from the hedonic model. Despite the introduction of five new health traits, the Hedonic Net Merit index weighting towards health increased only about 10 percentage points compared to a 17 percentage point increase in the USDA index. Production traits received about 11 percentage points less emphasis in the price versus a 16 percentage point decrease in Net Merit. The sluggish response appears to be related to the fact that dairy producers value physical traits more than both production and health traits.

Before it was introduced, the fertility traits was negatively related to price, likely due to the fact that fertility is negatively related to production traits such as milk yield. After its introduction, the trait increased in importance until finally becoming positively related to price in 2007. The trait most correlated with fertility, a measure of longevity, did not significantly change during this period, indicating that the increased importance of fertility was likely not related to an unrelated increase in the economic value of health traits. I also see that, in the period the fertility trait was introduced, the longevity trait factored less into price relative to the previous period. This is suggestive evidence that the longevity trait was used to indirectly select for fertility before its introduction.

These results have implications for releasing new product characteristics into markets in general. The adoption of a new characteristic will depend on how that new characteristic is correlated to existing characteristics that customers already use to select products. In this case, fertility was negatively correlated to existing desired characteristics and this may be one reason the trait took longer to factor positively in the price. Releasing new characteristics for products may be less effective as a way to change behavior when it goes against prior preferences.

This paper contributes to the literature using hedonic analysis to analyze input markets and to a smaller literature examining the specific case of cattle markets. The first application of the hedonic model to input markets was Ladd and Martin (1976) who called their model the “Input Characteristics Model” (ICM). This model is built off of the linear characteristics model of Lancaster (1966) and Gorman (1980) which models the demand side of the market. Hedonic input models have primarily been applied to agricultural goods such as wheat (Espinosa and Goodwin, 1991; Roberts et al., 2022) and beef cattle (Schroeder et al., 1988; Garber et al., 2022) due to their dual roles as both outputs and inputs depending on the place in the supply chain. A smaller literature has used the ICM to analyze dairy bull markets. Richards and Jeffrey (1996) and Schroeder, Espinosa and Goodwin (1992) both use cross-sections of dairy bull prices from Canada and the US to estimate hedonic models using the genetic traits of dairy bulls. Richards and Jeffrey (1996) use their hedonic model to calculate their own selection index and find that it predicts prices better than Canada’s most popular selection index, the Lifetime Profit Index.

My approach builds on this literature in two important ways. First, this is one of the few hedonic analyses to use panel data instead of cross-section data. Multiple time periods are especially important for this analysis since we would like to see how the valuation of characteristics changes over time. Having multiple years of data over the same products also allows us to distinguish between shifts in preferences over products and shifts in the types of products offered (Crawford and Neary, 2023; Banzhaf, 2021) Second, the data allow me to examine how innovation in product characteristics impacts the market for inputs. Crawford and Neary (2023) examines how expanding product characteristics in the market for cars impacts the measurement of inflation but does not explore how new characteristics factor into prices over time. This analysis is thus far the first to examine the expansion of characteristics in agricultural inputs and the speed at which firms adopt new characteristics.

2 Theoretical Framework

This theory model is a sketch of the linear characteristics model of Gorman (1980) and Lancaster (1966) combined with the insights of the Input Characteristics Model of Ladd and Martin (1976). The linear characteristics model for an input market assumes that there is a firm that needs k inputs and has a stock of each input z_k. To increase the stock of each input, the firm can only buy bundles of characteristics in the form of B_i. The "linear" in "linear characteristics model" derives from an assumption about how each bundle B_i increases the input stock z_k. The assumption says that z_k is equal to a linear function of the B_i that the firm has purchased:

$$z_k = \sum_{i=1}^{N} x_{ik} B_i \tag{1}$$

where x_{ik} is the amount of characteristic k that B_i delivers. The amount of z_k that the firm has depends on which bundles the firm buys (B_i) and how much of each k the bundle gives (x_{ik}). This assumption rules out the possibility that buying two bundles together somehow delivers more or less than the total k available in each B_i. The implication of this for dairy farming and genetics is that dairy farmers are assumed to view buying bulls as adding to the "stock" of each trait in their herd.

The objective of the firm is to maximize profits by buying bundles B_i which each have a price p_i:

$$max_B \quad \pi(z_1, ..., z_k) - \sum_{i=1}^{N} p_i B_i \quad \text{s.t.} \quad z_k = \sum_{i=1}^{N} x_{ik} B_i \quad \forall \quad k. \tag{2}$$

Schroeder, Espinosa and Goodwin (1992) and Richards and Jeffrey (1996) both point out that, in the case of a dairy herd, π is not only the current period's profits but actually the net present value of the future profits of the dairy herd. Regardless of the interpretation of π, the first-order conditions for this model are:

$$p_i = \sum_{k=1}^{K} w_k x_{ik} \quad \forall \quad i. \tag{3}$$

$$\text{s.t.} \quad w_k = \frac{\partial \pi}{\partial z_k} \tag{4}$$

Because of the linear form of Equation 1, each bundle's price p_i is a linear function of the amount of each input it delivers (x_{ik}) weighted by w_k, its marginal contribution to the firm's profits ($\frac{\partial \pi}{\partial z_k}$). Dairy farms buy bundles of genetic traits by breeding with bulls that will produce offspring. That offspring will produce milk and impact profits for the duration of its lifetime, so firms choose each bull to maximize the profits of that offspring's lifetime. Under these model assumptions, a bull's price can be described as a linear function of its genetic traits where each weight is that trait's contribution to the lifetime profit of each offspring.

Using Equation 3 as a regression model, we can use the prices of dairy bulls on the market and their genetic traits to estimate w_k. The hedonic coefficients w_k can be directly compared to the weights of the USDA's Net Merit index, ω_k. Net Merit is maintained and updated by the USDA and selects weights for genetic traits that represent lifetime profit (VanRaden, 2004). Calling these weights ω_k, we can represent the Net Merit index this way:

$$NM_i = \sum_{k=1}^{K} \omega_k x_{ik}. \tag{5}$$

Both w_k and ω_k represent the lifetime profit of increasing that trait. While ω_k changes when they are revised by the USDA, w_k changes when the perceived profitability of that trait changes in the market. One way to track the relationship between a trait's Net Merit's weight and its perceived profitability is to construct an alternative selection index (Richards and Jeffrey, 1996). Having calculated estimates $\hat{w}_k$, we can construct an alternative Net Merit index, call it "Hedonic Net Merit":

$$HNM_i = \sum_{k=1}^{K} \hat{w}_k x_{ik}. \tag{6}$$

As each trait's relative contribution to the market price changes, so will its weight in the hedonic index.

To understand the impact of introducing new traits, Crawford and Neary (2023) provides a theoretical framing that characterizes the development of new characteristics as the loosening of a constraint. Specifically, they assume that, before a new characteristic is released to the market, the buyer of the product is only allowed to buy products with a fixed value of that characteristic. For example, before cars have backing cameras consumers are constrained to buy cars where that characteristic is fixed at "no backing camera." After backing cameras are introduced into cars, the constraint is taken away and consumers can choose products with different levels of that characteristic.

This framing is helpful for the case of cattle genetics but needs to be modified in one important way: cattle are not "constrained" to one level of a trait before that trait is known. Before backing cameras are invented for cars, it can be safely assumed that every car built possesses a specific level of that trait: "no backing camera." If we consider the case of a fertility trait in cattle genetics, no such constraint would apply. Cattle all possess varying levels of fertility before the trait is known by the supply side (breeders) or the demand side (dairy farms). The only difference between before and after is that now both sides have a clear measurement of the characteristic. Since fertility is an economically important trait to dairy farmers that they can observe, this implies that cattle breeders and dairy farmers could have incorporated fertility into their decisions by **indirectly** selecting the characteristic by selecting characteristics correlated to fertility. The constraint then is not the ability to choose a different level of the characteristic, as in Crawford and Neary

(2023), but rather the ability to select **accurately**.

A theoretical framing that is even more relevant is the literature on the effect of pollution information on the price of housing (Mastromonaco, 2015). Much like dairy farmers, a consumer buying a house might be able to observe pollution and thus have an educated guess about its level in a neighborhood. The release of objective pollution estimates like the Toxics Release Inventory (TRI) is similarly the lifting of an information constraint for both buyers and sellers of houses. This implication of this is that the release of new information on a characteristic affects both the demand for that characteristic and the demand for any "proxy characteristic" that was used to indirectly select if before it was known. In the case of cattle genetics, there are known correlations between production, health, and physical characteristics, so it is very likely dairy farmers selected certain characteristics before the information release in order to indirectly select on characteristics that were not yet published.

In a hedonic regression, we can measure an increase in demand for a characteristic by looking at whether it factors more into price after the characteristic is known. The magnitude of this information effect depends on two factors. First, it depends on the extent to which dairy farmers could accurately select for it indirectly through other characteristics before it was known. If farmers could perfectly select their preferred level of the unknown characteristic using other traits, there would no change in how the characteristic factors into price. If farmers can only imperfectly select, the publication of the new characteristic would change how it factors into the bull's price. Second, the information impact depends on the economic importance of the new characteristic. If the new characteristic is unimportant to the dairy farm's profits, the information impact will be small. Similarly, if the economic importance of that characteristic changes over time, we might confuse the impact of the loosening of the information constraint for an updated understanding of its economic importance.

Another wrinkle to this specific context is the ability of the supply side to react to this information. In most hedonic models, the supply side is held fixed (Rosen, 1974). In cross-sectional data, this is easier to accept since the products on the market are not changing. In dynamic studies of housing prices, a fixed supply side is also acceptable over a short enough time frame. Once new information is published, housing developers need several years to factor the information into the construction decisions because of lags in permitting and construction time. In contrast, dairy breeders need only about three years to produce new bulls once the information is revealed. This means that we need to distinguish between two effects: the "repricing effect" and an eventual supply-side response. The repricing effect is when dairy breeders change the prices of the dairy bulls on the market after the revelation of this information. The supply-side response is when breeders actually change their decisions about breeding after the information in order to produce more future cattle with more or less of the characteristic. The repricing effect can be isolated by only looking at animals sold before and after the new characteristic is published.

3 Data and Methodology

The National Association of Animal Breeders (NAAB), a trade organization representing all of the major livestock genetics companies selling bulls in the United States, publishes the posted price and genetic traits of all of the bulls being sold by their members. Traits and prices are posted three times a year at the same time that each bull's predicted genetic traits are calculated and posted publicly by the Council on Dairy Cattle Breeding. My data is from the NAAB's published lists from the years 2000 to 2010 and represents over 24,000 dairy bulls, both foreign and domestic, sold during this period. When a new genetic trait is published, the USDA not only calculates it for the bulls currently available but also bulls that are already out of the data. The upshot of this is that we have measurements of a bull's genetic traits and its price before and after the new trait is published.

The set of genetic characteristics published in this period are shown in Table 1. The characteristics can be broadly categorized as production (traits having to do with milk production), health (traits having to do with longevity, sickness, and fertility), and physical (traits having to do with the physical characteristics of the animal, also called "type"). To help dairy farmers understand how each characteristic contributes to profit, the USDA publishes an index combining the characteristics called "Net Merit." The Net Merit index is reported in units of dollars, meaning each trait is given a weight which represents their contribution to lifetime profit of the bull's offspring. The Net Merit index was updated in August of three different years during this period to accommodate different traits: 2000, 2003, and 2006.

Table 1 shows how the relative weights of each category of traits has changed in the three updates. At the beginning of this sample, Net Merit put about 60% of its emphasis on production traits versus about 23% on health traits. After the 2006 revision, production was only 46% of the index and health was about 40%. The decline in production is mainly explained by a decline in the weight on protein and milk volume. The increase is health is explained by a greater emphasis on productive life (lifespan) and the inclusion of three more traits: fertility (called "daughter pregnancy rate"), birthing difficulty, and calf stillbirth rate.

Table 2 shows the average trait values during each period and its percentage growth rate over time.[1] From 2000 to 2009, all production traits increased between 15 and 25%. Productive life has increased 61% and somatic cell score and conception difficulty all decreased (meaning health has improved). Daughter pregnancy rate, a measure of fertility, also improved during this period. All three of the type traits increased over this period, with udder composite having one of the highest growth rate of all the indices: 96%. De-

[1] Genetic traits in dairy are by default "base-adjusted," meaning every three or so years the average value is subtracted from every bull's trait value. If a trait is above zero, this means it has more of the trait than that period's average (+50 fat pounds means 50 more pounds than the average bull). If a trait is negative, this means it has less of the trait than the average bull. In order to see genetic improvement in the data, I have undone the base adjustments from 2000 to 2010 so that every trait is relative to the average bull in 2000.

Table 1: USDA Index Relative Weights (%)

Category	Index Revisions		
Trait	2000	2003	2006
Production	**61.91**	**55.48**	**44.84**
Milk (lbs)	4.58	0.0	0.00
Fat (lbs)	20.94	22.38	22.83
Protein (lbs)	36.39	33.1	22.01
Health	**23.12**	**30.70**	**42.08**
Productive Life (months)	13.7	10.74	17.16
Somatic Cell Score	-9.42	-9.14	-8.45
Daughter Pregnancy Rate*	-	6.55	8.29
Birthing Difficulty (Male)*	-	-2.34	-1.92
Birthing Difficulty (Female)*	-	-1.93	-1.18
Stillbirth Rate (Male)**	-	-	-1.92
Stillbirth Rate (Female)**	-	-	-3.16
Physical (“Type”)	**14.98**	**13.83**	**13.09**
Udder Composite	6.92	7.09	6.15
Feet and Legs Composite	4.04	3.63	3.22
Body Size Composite	-4.02	-3.11	-3.71

* Introduced in 2003

** Introduced in 2006

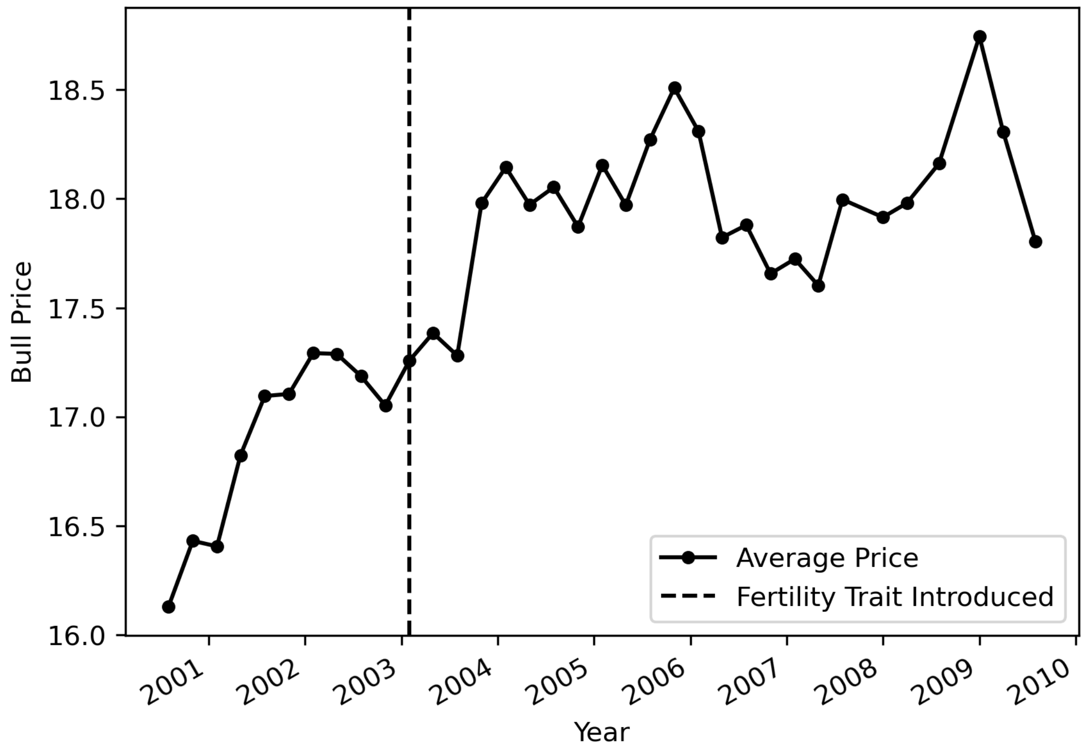
Table 2: Bull Characteristics Over Time

Category Trait	Average, 2000-2003	Average, 2003-2006	Average, 2006-2009	% Change, 2000 to 2009
Production				
Milk (lbs)	1747.81	1879.84	1999.42	14.40
Fat (lbs)	57.21	65.58	73.34	28.19
Protein (lbs)	56.84	62.57	66.12	16.33
Health				
Productive Life (months)	1.32	1.47	2.14	62.67
Somatic Cell Score	3.22	3.21	3.18	-1.31
Daughter Pregnancy Rate*	-0.14	0.03	-0.08	-41.95
Conception Difficulty (Male)*	8.90	8.93	8.94	0.49
Conception Difficulty (Female)*	6.84	6.02	5.35	-21.78
Stillbirth Rate (Male)*	8.02	7.79	7.83	-2.38
Stillbirth Rate (Female)*	7.54	7.64	7.65	1.46
Type (Production)				
Udder Composite	0.91	1.18	1.79	95.97
Feet and Legs Composite	0.88	0.87	1.15	30.13
Body Size Composite	0.75	0.63	0.78	2.87

Note: all trait values are relative to the 2000 average.

** Trait interpolated to previous periods using last know value.*

Figure 1: Bull Price over Time



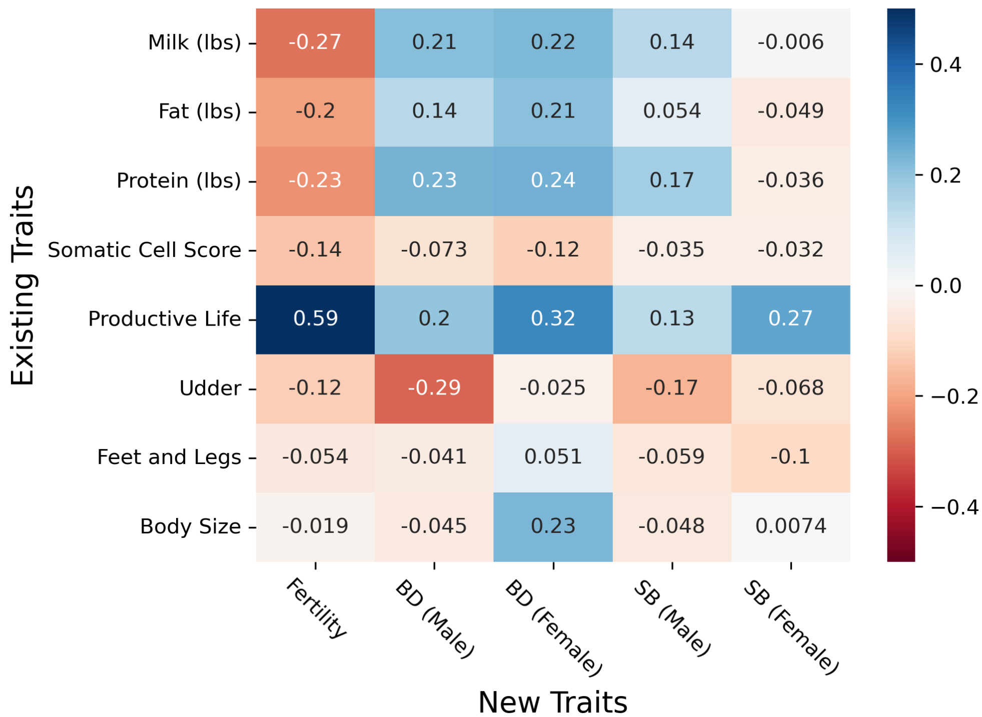
Note: adjusted to 2000 CPI index.

spite having a negative weight in Net Merit, the body size index grew 20% from 2000 to 2009.

Figure 1 shows the average bull price in each evaluation period from August 2000 to December 2009. Reflecting the increase in traits, bull prices increased from $16.5 to about $19 (a 15% increase). From the first period in the data until the 2003 revision, the average price climbed from $16.5 to about $18. After the 2003 revision, price increased another dollar but then stayed around $19 for the remainder of the period.

An important consideration for this analysis is the existing correlations between existing traits and the introduced traits. Our theoretical framework tells us that, in the absence of perfect information, dairy farmers will use other traits to select the traits they need. Figure 2 shows the correlations between traits available the whole period, the y-axis, and traits introduced during that period, the x-axis. In this analysis, I will focus on analyzing

Figure 2: Correlations Between Old Traits and Introduced Traits



the fertility trait, the first column of the figure. Fertility is negative correlated to production traits and has a small to no correlation with physical traits such as udder, feet, and body size. It's strongest correlation is with a trait called "productive life" which measures the effective, productive lifespan of the cow. Productive life is calculated using death and "culling" (removal of the cow from the herd) records available on each bull's daughters. Given the cattle are often culled for being infertile, cows that live longer in the herd are very likely to be more fertile. In contrast, energy devoted to fertility is generally diverted away from milk production, making a tradeoff between milk production ability and fertility.

The first order condition of the linear characteristics model, Equation 3, implies that we can use data on prices p_{it} and genetic traits x_{ikt} of each bull i in time t to estimate w_k.

The first regression model takes the form:

$$p_{it} = \sum_{k=1}^{K} w_k x_{ikt} + \beta Z_{it} + \epsilon_{it}. \tag{7}$$

The first step to understanding the incorporation of health traits over time is to compare the coefficients from the hedonic model to the weights of the Net Merit index. Comparing hedonic weights w_k to Net Merit weights ω_k is easier if the weights are relative weights that are independent of the units of each trait (interpreted as percentage of emphasis on each trait). Net Merit "relative weights" are calculated by dividing each weight by the standard deviation of the trait (making it in units of standard deviation), taking the absolute value of each trait, and dividing each trait by the sum of those absolute values.[2] To convert w_k weights into relative weights, each trait x_{ikt} is standardized by subtracting the sample mean and dividing by the sample standard deviation. The resulting weights w_k can then be compared even when each trait has a different unit. To get the relative weights, each w_k is divided by the sum of the absolute value of the traits (just as Net Merit does).

In the case that there are omitted variables that correlate to both x_{ikt} and p_{it}, I include a vector of control variables Z_{it} within this regression model. One potential source of endogeneity is the bull's popularity or fame. To control for these impacts, I include the bull's age, the number of daughters in its evaluation (which reflects the amount of farms purchasing that bull), a fixed effect for the stud code (the company that sells the bull), and a fixed effect for the name of the stud farm that the bull comes from.[3] I also include fixed effects for each evaluation period and each bull's birth year.

The next step is to examine how the hedonic coefficients for new characteristics change

[2]See the 2000 Net Merit Revision for more details on this calculation.

[3]In the dairy industry, stud farms are responsible for making crosses of different genetic lines to produce bulls whose semen can be sold on the market. The stud farm's name is almost always contained in the first part of the bull's name. For example, the bull "Braedale Goldwyn" is from Braedale farms and goes by the short name "Goldwyn." Using each bull's full name, we extracted the name of the stud farm. Once a stud farm produces a bull, the farm may sell the rights of distribution to a company that is a member of the NAAB (e.g. ABS, Select Sires, Genex). The name of the company selling the bull's semen is represented by the stud code.

after they are known by the market. Our modified approach is:

$$p_{it} = \sum_{\ell=1}^{L} \sum_{h=1}^{H} \beta_h^\ell x_i^h \times 1\{t = \ell\} + \sum_{k=1}^{K} \beta_k x_i^k + \gamma Z_i + \epsilon it$$

where β_ℓ^h is the impact of the new trait h on price in period ℓ. If the release of that health trait has a significant impact on pricing, we anticipate the coefficient β_h^ℓ to significantly change after its introduction. This approach is similar to the difference-in-difference approach of other analyses of the impact of new information on the pricing of housing (Banzhaf, 2021; Barwick et al., 2019).

In the case of fertility, I hypothesize that the publication of the trait will increase the capitalization of fertility into bull price. As Table 1 shows, the USDA considers fertility to be positively correlated to profits. If dairy farmers can only imperfectly select on fertility before the trait is published, I expect the hedonic coefficient to increase relative to its previous periods. Similarly, I expect a change in the weighting of productive life since it is most likely to be used as a proxy for fertility when fertility was not clearly known by the market.

4 Results

I first present the coefficients of the hedonic model (Equation 7) which uses the logarithm of price as an outcome to lessen the influence of any outliers. Each trait is standardized by subtracting the mean and dividing by the standard deviation. Since all the traits are standardized, the relative weights can be obtained by dividing each one by the sum of the absolute value of all of the traits. I estimate the model using three different time periods based on the three Net Merit revisions: 2000-2003, 2003-2006, and 2006-2009. For each of these periods, I compare the relative weights of the hedonic model to the Net Merit weights in each of those revisions. Then, I estimate a difference-in-differences style model by comparing the capitalization of fertility into price versus its potential “proxy” characteristic, productive life.

4.1 Hedonic Model

Table 3: Hedonic Model Results

	log(Price)			
	Pooled	2000-2003	2003-2006	2006-2011
Production				
Milk (lbs)	−0.040	0.031	−0.005	0.042
	(0.049)	(0.061)	(0.082)	(0.067)
Fat (lbs)	0.060***	0.084***	0.047	0.098***
	(0.017)	(0.022)	(0.030)	(0.024)
Protein (lbs)	0.102***	0.129***	0.116***	0.077***
	(0.019)	(0.020)	(0.030)	(0.020)
Health				
Productive Life (months)	0.066***	0.045***	0.066***	0.059***
	(0.009)	(0.010)	(0.013)	(0.012)
Somatic Cell Score	−0.017***	−0.004	−0.021***	−0.027***
	(0.005)	(0.008)	(0.005)	(0.005)
Daughter Pregnancy Rate			−0.014	0.019**
			(0.009)	(0.009)
Calving Ability				0.027**
				(0.011)
Conception Difficulty (male)			0.010	
			(0.021)	
Conception Difficulty (female)			−0.009	
			(0.010)	
Type				
Udder Composite	0.110***	0.164***	0.159**	0.188***
	(0.040)	(0.054)	(0.063)	(0.059)
Feet and Legs Composite	0.087***	0.082***	0.099***	0.081***
	(0.008)	(0.010)	(0.012)	(0.009)
Body Size Composite	0.034*	0.045*	0.048*	0.076**
	(0.020)	(0.025)	(0.028)	(0.030)
Observations	24,052	7,723	7,569	7,140
Adjusted R^2	0.596	0.656	0.622	0.643

Note: *p<0.1; **p<0.05; ***p<0.01

Table 3 shows the results of the hedonic model using the logarithm of price as the out-

Table 4: Relative Weights, Hedonic and Net Merit

	2000-2003		2003-2006		2006-2009	
	Hedonic	Net Merit	Hedonic	Net Merit	Hedonic	Net Merit
Production						
Milk (lbs)	5.365	4.579	-0.877	0.0	6.07	0.0
Fat (lbs)	14.329***	20.94	7.868	22.376	14.115***	23.421
Protein (lbs)	22.07***	36.387	19.549***	33.104	11.178***	22.583
Health						
Productive Life (months)	7.647***	13.699	11.108***	10.736	8.449***	17.609
Somatic Cell Score	-0.702	-9.418	-3.513***	-9.14	-3.884***	-8.675
Daughter Pregnancy Rate			-2.429	6.552	2.692**	8.501
Calving Ability					3.847**	5.783
Birthing Difficulty (male)			1.713	-2.34		
Birthing Difficulty (female)			-1.56	-1.927		
Type						
Udder Composite	28.01***	6.917	26.614**	7.086	27.111***	6.315
Feet and Legs Composite	14.12***	4.036	16.692***	3.634	11.712***	3.308
Body Size Composite	7.758*	-4.024	8.077*	-3.105	10.942**	-3.805

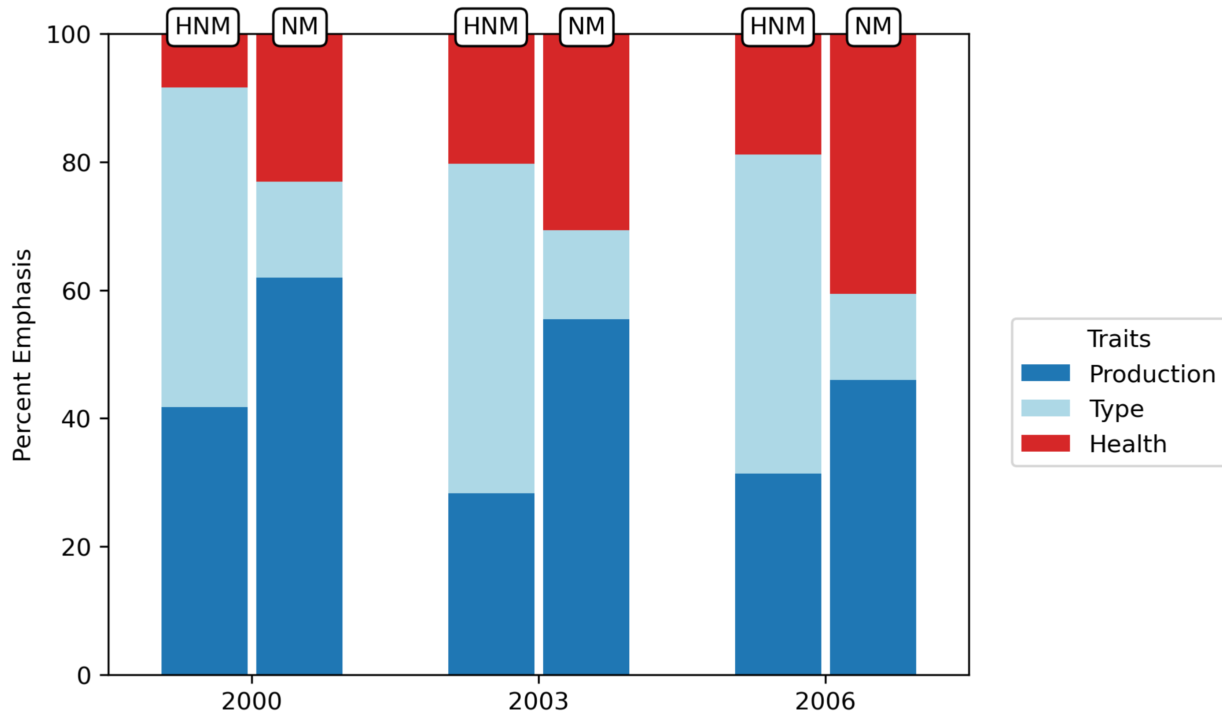
Note: *p<0.1; **p<0.05; ***p<0.01

come.[4] Milk production independent of fat and protein is not a significant determinant of price. Fat and protein production, measured in pounds, are positively related to price since this is the metric that most farmers are paid on. The fertility trait, daughter pregnancy rate, is negatively correlated to price just after its introduction in 2003 but positive after 2006. All three physical traits, udder, feet, and body size, positively impact price. The positive impact of body size is striking because the body size composite receives a negative weight in the Net Merit index for this whole period.

Table 4 shows the relative weights of the Hedonic Net Merit (HNM) and the Net Merit (NM) index in each time period. In 2000, fat and protein were 14 and 22% of the HNM index and 20 and 36% of the NM index. By 2006, fat was still 14% but protein went down to 11% in the HNM. This mirrors protein's shift from 36% to 23% in the NM, indicating that

[4]In later versions of Net Merit, birthing traits are combined into one index called "calving ability." To compare these estimates to Net Merit weights, I combine the birthing traits with the same index formula and estimate the hedonic coefficient for that index instead of the traits separately.

Figure 3: Trait Emphasis by Year



changes in NM may have had an influence on price. While health traits are significant determinants of price, they have a much smaller weight in the HNM index than in NM. Type traits receive the highest weight in the HNM. The udder index is about 27% of the HNM but only about 6% of the NM. Similarly, the feet and legs index is between 11% and 16% of the HNM but only between 3-4% in the NM. Body size receives a positive weight in the HNM and is between 8% and 10% of the index.

Figure 3 shows the shift in emphasis over time visually. In both indices, health traits (represented by the red bar) grow in influence over time. This shift appears to be driven primarily by including more traits in the index around health. HNM has a less than 10% emphasis on health in 2000 but grows to about 20% in 2003 thanks to the inclusion of more traits. Between 2003 and 2006, the HNM index does not weight more towards health even though NM increased its emphasis on health. Physical traits take up close to 50% of the HNM but are less than 25% of the NM. As health traits are included into NM, production traits receive less emphasis but type traits go unchanged.

While health traits become a greater part of the price eventually, they factor less into price than in Net Merit. Despite the introduction of five new health traits, the Hedonic Net Merit index weighting towards health increased only about 10 percentage points compared to a 17 percentage point increase in Net Merit. Production traits received about 11 percentage points less emphasis in the price versus a 16 percentage point decrease in Net Merit. The sluggish response appears to be related to the fact that dairy producers value physical traits more than both production and health traits.

4.2 The Introduction of Fertility

For this stage of the analysis, I focus specifically on two traits: fertility and productive life. Since fertility is calculated for all bulls after the trait is introduced, I can "backfill" fertility trait values for bulls born before the trait was known to the public. I then interact both fertility and productive life with time fixed-effects in order to allow the hedonic coefficient to change over time.[5] Fertility traits were first published at the beginning of 2003, making last evaluation period of 2002, November 2002, our "base period."

Figure 4 shows a coefficient plot of fertility and longevity traits relative to the period before fertility's introduction. In the period immediately following the release, fertility increased its importance in price while longevity decreased. In the next period, both coefficients drop down to their pre-2003 level. Over time, fertility rises to be more important in the price while longevity stays the same. These results are consistent with longevity being treated as a proxy trait for fertility since it was devalued immediately after the publication of the fertility trait. Since longevity does not become more important to the price over time, it is unlikely that the increased importance of fertility is due to an independent appreciation of cattle health traits among dairy farmers.

Figure 5 shows how fertility and longevity factor into price from 2000 to 2009 using

[5] Since the other traits are uninteracted, this model assumes that the contribution of other traits to price do not change over time. This is an assumption that can be relaxed in future work with a variety of model approaches.

Figure 4: Fertility versus Longevity, 2000-2007 (Base: November, 2002)

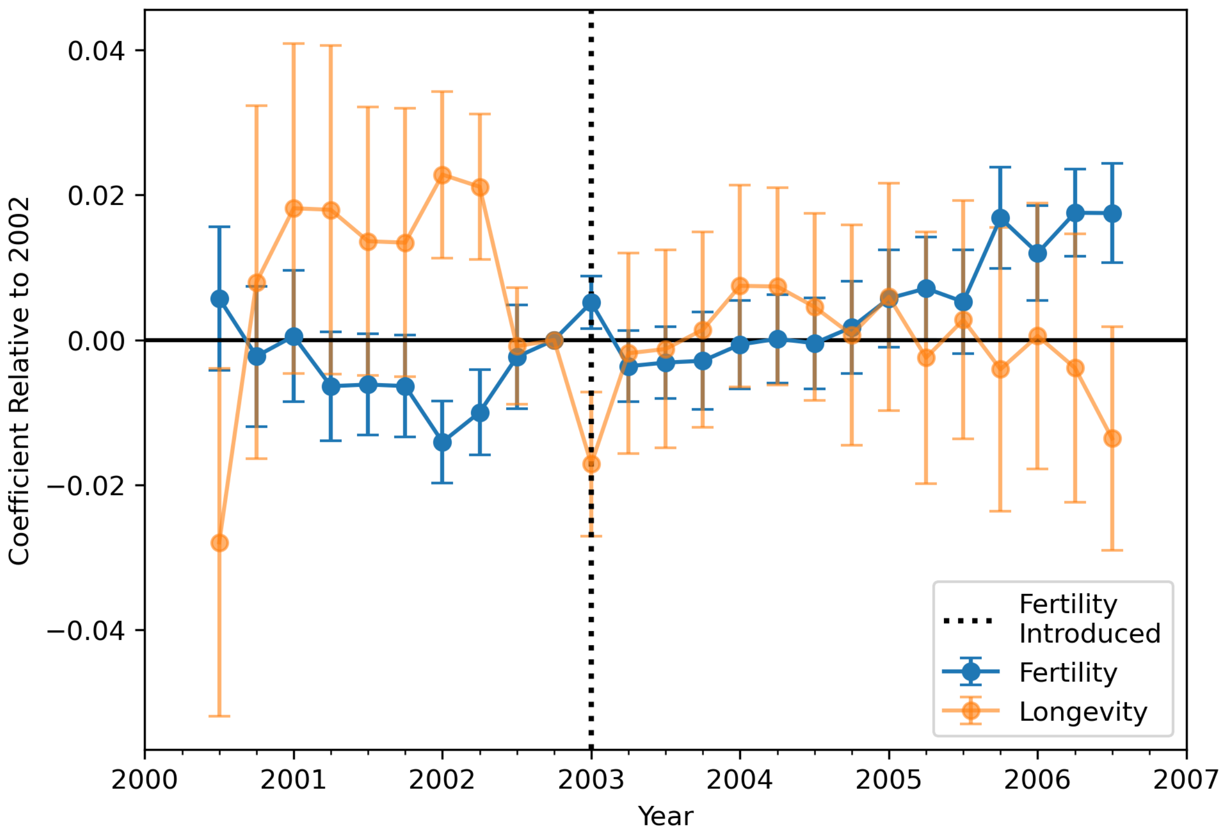


Figure 5: Fertility versus Longevity, 2000-2009

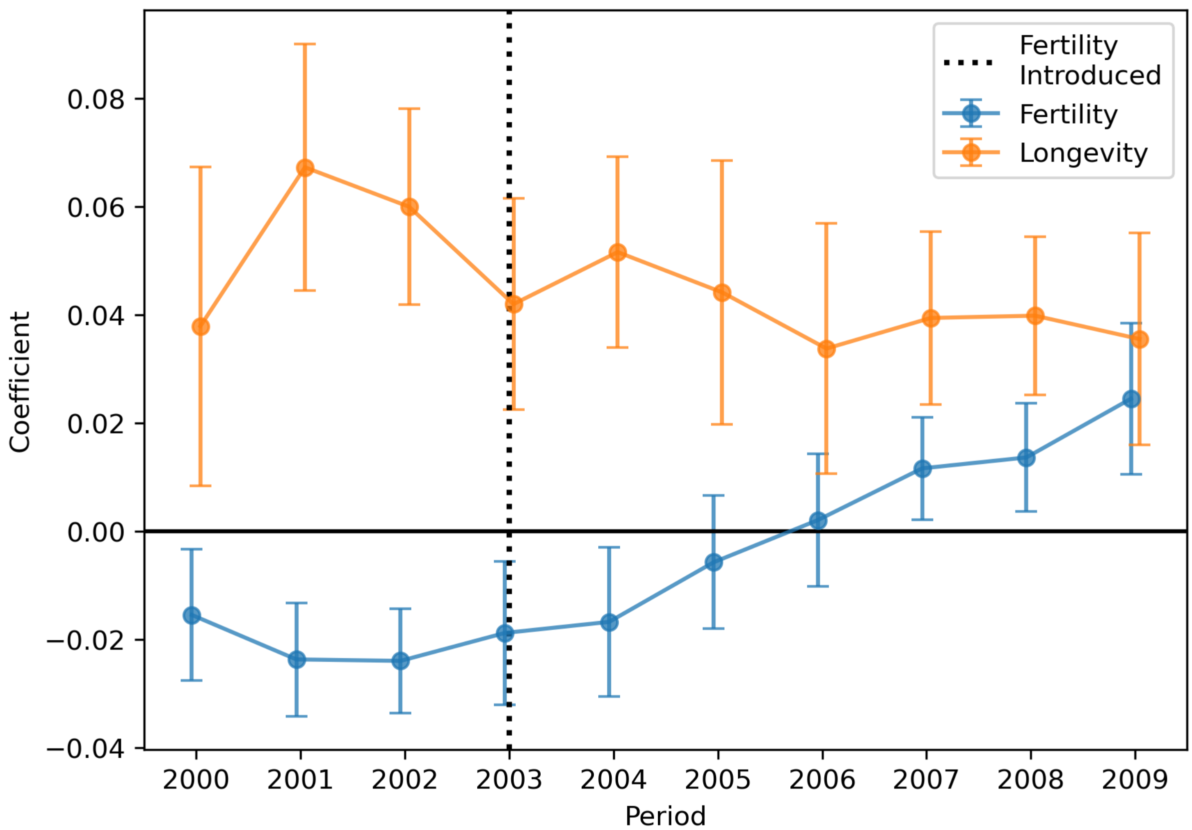
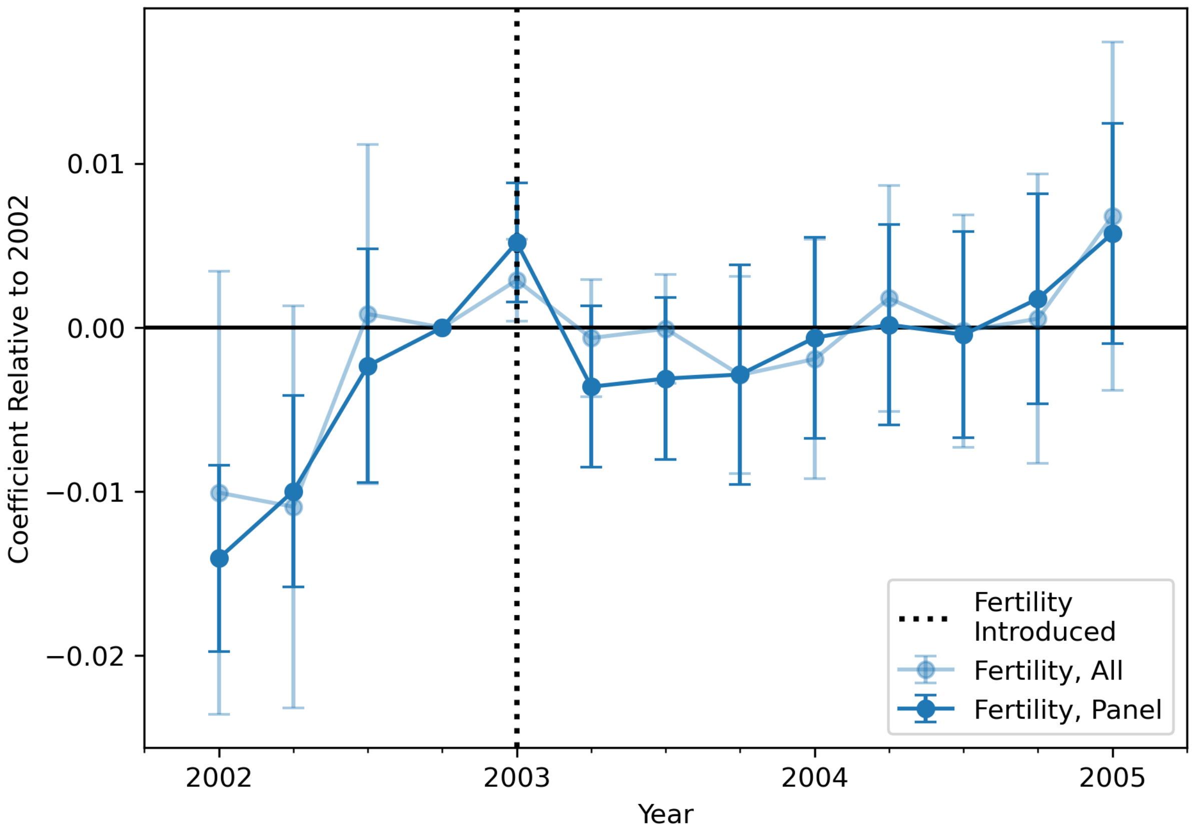


Figure 6: Fertility Trait, All Bulls and Panel, 2002-2005



years instead of periods. Unlike Figure 4, these coefficients are not relative to a base period so we can see how they capitalize into prices over time. As we see in Table 3, fertility starts out negatively related to price but gradually climbs over time. In 2007, it becomes positively correlated to price indicating that fertility is finally associated positively with profits instead of negatively. Longevity scarcely changes over time, remaining positively related to price in the entire sample. The gradual increase in the coefficient on fertility may reflect a learning process for dairy farmers. Upon its release, it is a trait the dairy farmers inherently select against due to its correlation with other production traits. Over time, dairy farms adopt the trait and it begins factoring positively into price even independent of other traits.

The last result in Figure 6 presents the coefficient for fertility over time but in two samples: the sample of all bulls and a sample of bulls who were alive before and after the fertility trait was introduced. This helps us determine to what extent changes in the fertility coefficient are driven by repricing existing bulls (light blue) or by suppliers producing new bulls with different traits (dark blue). The coefficients are similar in both samples, including the bump in the coefficient following its introduction. This indicates that the bump in the significance of fertility to price was from firms repricing their existing bulls and not from flooding the market with new bulls.

5 Conclusion

The objective of this study was to study the capitalization of new characteristics into the prices of firm inputs. In this case, dairy farmers saw the release of new genetic traits for the market for dairy bulls. Using ten years of data on dairy bull prices and traits, I find that the introduction of health traits did eventually factor into prices. Looking at fertility as one example, I see a small bump in the economic weight of fertility in bull prices after its introduction and an almost equivalent drop in the weight of longevity, a trait highly correlated to fertility. Over time, fertility capitalized positively into price instead of negatively which could be indicative of dairy farmers learning the value of the trait over time. The initial increase in the importance of fertility appears to be related to repricing existing bulls instead of dairy breeders producing new bulls in reaction to the trait's publication.

This research provides some interesting directions for future research. First, a suitable theoretical framework is needed to understand the circumstances under which the introduction of new product characteristics will impact the market for inputs. Using other models as a starting point, there could be a theoretical framing that explains and even predicts the impact of new characteristics on buying behavior and consequently how the inputs are priced. Second, the application here is limited to the dairy bull market but could be expanded to other input markets. Similar analyses of input markets in other contexts, for example another genetic input like seeds, might lead to a more robust conclusion about the impact of expanding characteristics in input markets.

References

Banzhaf, H. Spencer. (2021, August). Difference-in-Differences Hedonics. *Journal of Political Economy 129*(8), 2385–2414. Publisher: The University of Chicago Press.

Barwick, Panle Jia., Shanjun. Li, Liguo. Lin, and Eric. Zou (2019). From fog to smog: The value of pollution information. Technical report, National Bureau of Economic Research.

Crawford, Ian. and J. Peter. Neary (2023, May). New Characteristics and Hedonic Price Index Numbers. *The Review of Economics and Statistics 105*(3), 665–682.

Espinosa, Juan A.. and Barry K.. Goodwin (1991). Hedonic Price Estimation for Kansas Wheat Characteristics. *Western Journal of Agricultural Economics 16*(1), 72–85. Publisher: Western Agricultural Economics Association.

Garber, Ben., Jeffrey. Alwang, George W.. Norton, and John. Bovay (2022, February). Beef and the Bottom Line: The Effect of Value-Added Certification on Feeder Cattle Profitability. *Journal of Agricultural and Applied Economics 54*(1), 157–174. Publisher: Cambridge University Press.

Gorman, William M.. (1980). A possible procedure for analysing quality differentials in the egg market. *The Review of Economic Studies 47*(5), 843–856. Publisher: JSTOR.

Hazel, L. N.. (1943, November). The Genetic Basis for Constructing Selection Indexes. *Genetics 28*(6), 476–490. 01519.

Ladd, George W.. and Marvin B.. Martin (1976). Prices and demands for input characteristics. *American Journal of Agricultural Economics 58*(1), 21–30. Publisher: Wiley Online Library.

Lancaster, Kelvin J.. (1966). A new approach to consumer theory. *Journal of political economy 74*(2), 132–157. Publisher: The University of Chicago Press.

Mastromonaco, Ralph. (2015, May). Do environmental right-to-know laws affect markets? Capitalization of information in the toxic release inventory. *Journal of Environmental Economics and Management 71*, 54–70.

Richards, Timothy J.. and Scott R.. Jeffrey (1996). Establishing indices of genetic merit using hedonic pricing: an application to dairy bulls in Alberta. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie 44*(3), 251–264. Publisher: Wiley Online Library.

Roberts, Shane., Kathleen. Brooks, Lia. Nogueira, and Cory G.. Walters (2022, April). The role of quality characteristics in pricing hard red winter wheat. *Food Policy 108*, 102246.

Rosen, Sherwin. (1974, January). Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. *Journal of Political Economy 82*(1), 34–55.

Schroeder, Ted., James. Mintert, Frank. Brazle, and Orlen. Grunewald (1988). Factors Affecting Feeder Cattle Price Differentials. *Western Journal of Agricultural Economics 13*(1), 71–81. Publisher: Western Agricultural Economics Association.

Schroeder, Ted C.., Juan A.. Espinosa, and Barry K.. Goodwin (1992). The value of genetic traits in purebred dairy bull services. *Applied Economic Perspectives and Policy 14*(2), 215–226. Publisher: Wiley Online Library.

VanRaden, P. M.. (2004, October). Invited Review: Selection on Net Merit to Improve Lifetime Profit. *Journal of Dairy Science 87*(10), 3125–3131. 00098.