Economic analysis by comparing different artificial insemination techniques in pork production

by

Juan A Orozco

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Dr. Glynn Tonsor

ABSTRACT

The pork industry has evolved considerably over recent decades. Competition has intensified as vertical integration continues across the production chain, and companies increasingly operate across all stages from genetics to the slaughterhouse. In this environment, producers pursue new technologies to improve performance and efficiency in labor, health, biosecurity, nutrition, equipment, and genetics. The result is consistent year-over-year improvement in production performance; yet because pork is a commodity, input costs remain the primary determinant of profitability. Feed cost is historically the most significant input, with facility cost and labor increasingly important in recent years.

Several structural challenges define the current industry landscape. Disease pressure, particularly PRRS, PEDv, ASF, and CSF represents one of the most disruptive forces facing producers globally, creating supply chain instability and substantial economic losses in affected regions. Labor availability continues to constrain operations, especially in the United States, where agriculture competes with other sectors for a shrinking workforce.

At the intersection of two of the most dynamic areas of the industry; reproduction and genetics, lies the central question of this thesis. The last decades at the Genetic Transfer Center (GTC) level have been defined by a sustained effort to reduce semen dose concentration and volume, enabling a single genetically superior boar to reach more females. Simultaneously, genetic programs have focused on developing economically efficient, more robust populations, including novel biotechnologies such as PRRS-resistant pigs that may significantly impact the industry in the mid- to long-term. Combining these two trajectories, reproductive efficiency and genetic dissemination require an evaluation of

where the industry currently stands, which technologies can accelerate the speed of genetic dissemination, and whether a measurable economic incentive exists to adopt these techniques at a greater scale.

This thesis presents an economic analysis of the U.S. swine industry focused on three artificial insemination techniques: Cervical Artificial Insemination (CAI), Post-Cervical Artificial Insemination (PCAI), and Deep Intra-Uterine Insemination (DIUI). The analysis evaluates whether these techniques generate different economic outcomes across the four main production stages: Genetic Transfer Centers, Sow Farms, Wean-to-Finish Farms, and the Slaughterhouse. A Net Present Value framework is applied at each stage and at the integrated chain level for a representative 5,000-sow U.S. commercial operation, using the risk-differentiated discount rate framework of 7% for established CAI, 8% for PCAI, and 10% for DIUI.

Results demonstrate substantial positive incremental NPV across the industry chain when PCAI or DIUI is paired with semen from genetically superior boars. Over a five-year horizon, PCAI with higher-index boars (Scenario C) generates approximately $4.97 million of incremental NPV versus the CAI baseline, equivalent to $995 per sow. DIUI with elite boars (Scenario D) generates approximately $5.99 million, or $1,197 per sow. By contrast, PCAI implemented with the same boar genetic level as CAI (Scenario B) destroys approximately $1.47 million of value, or −$295 per sow, because the modest labor and dose-yield savings do not compensate for the catheter cost premium and the implementation risk premium embedded in the discount rate. The full economic benefit of PCAI is therefore only realized when the GTC and Sow Farm adopt the technology concurrently, with reduced dose concentration at the GTC level enabling more aggressive boar selection. Half-implementation captures a fraction of the available value, and these findings carry direct implications for the commercial deployment of emerging biotechnologies including PRRS-resistant genetics, where semen supply constraints make reduced-dose PCAI not an option but a necessity.

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CHAPTER I: INTRODUCTION

The tendency of the last several decades in the swine industry has been to increase production efficiency in an increasingly competitive market. That efficiency is achieved through the implementation of management practices and technologies that reduce costs and improve performance across the production chain. Because pork is a commodity, production economics are governed primarily by input prices; feed, facilities, labor, health-related costs, and logistics, among others. Companies therefore compete not on price alone but with their ability to produce high-quality pork at lower cost, and that competition drives continuous research into more efficient production methods across every area of the business.

This thesis is motivated by the recognition that limited information and corresponding economic analysis currently exists comparing different artificial insemination techniques across the full pork production chain. The magnitude of efficiency gains from adopting newer techniques requires direct economic assessment before adoption can be justified at scale and that assessment is what this work provides.

Genetic companies have done an outstanding job improving both the productive and reproductive traits of commercial animals. This improvement has resulted in populations with meaningfully better reproductive performance, including litter size, farrowing rate, wean-to-estrus interval, and sow longevity, as well as superior productive performance in traits such as feed conversion ratio, average daily gain, days to market, and survival rate. Carcass yield, lean percentage, and product quality have also improved substantially. These gains have been made possible through the integrated dissemination of superior genetics alongside advances in nutrition and disease control, and they are reflected in the consistent year-over-year improvement in production performance observed across the industry.

A critical factor that has been, and will continue to be, central to genetic progress is the efficiency of genetic dissemination. The rate at which superior genes from elite sires reach a greater number of females directly determines the speed of genetic improvement across a population. New AI techniques are sought precisely because they offer a more efficient means of disseminating genes from genetically superior boars to a greater number of females, generating a positive impact on key production traits and, consequently, on the economics of the farm and the industry.

The genetic index is an estimate of the cumulative dollar value of each animal's genetic potential across all traits in the selection objective. An index value is calculated for each animal based on its own performance data and, where available, the performance of relatives. Selection is then based on ranking individuals by index value (T.S. Stewart 2006). The index score of a given animal estimates how much better or worse it is expected to perform compared with the population average. When breeding a female, the sire's genes are inherited by the progeny, and offspring are expected to perform better or worse depending on the estimated breeding index values for economically important traits as litter size, average daily gain, mortality, days to market, and feed conversion ratio. Boars with higher index values are therefore expected to transmit traits that improve offspring performance and generate measurable economic benefits by reducing production costs downstream.

By breeding high-indexed females with the highest-indexed boars, a producer can expect a meaningful economic impact through improved offspring production performance.

If PCAI or DIUI provide the opportunity to disseminate superior genetics to a significantly greater number of females by increasing the boar-to-sow ratio the result is higher profits not only at the GTC level but across all production stages. This would represent a compelling incentive for industry-wide adoption, analogous to the transition from natural mating to cervical AI that reshaped the industry in previous decades.

What differentiates AI techniques is the site of semen deposition within the female reproductive tract, the sperm cell concentration, and the volume per dose. These differences directly affect the boar-to-sow ratio and therefore the scale of genetic influence a single sire can have. PCAI and DIUI reduce the diluent volume and number of spermatozoa required per dose while maintaining the farrowing rate, total born, and born alive comparable to CAI. This reduction in dose requirements either decreases the number of boars needed in a GTC for a given sow population or increases the number of doses available from each boar both outcomes generating direct economic benefit at the GTC level.

The boar-to-sow ratio illustrates this genetic dissemination advantage concisely. Under CAI, the ratio is approximately 1:150; meaning the highest-indexed boar in a GTC can directly impact only 150 females. Under PCAI, that ratio changes to approximately 1:450, tripling the number of females that receive genetics from that same superior animal. Under DIUI, the ratio extends to approximately 1:3,000; enabling a single elite boar to influence a dramatically larger female population. As the boar-to-sow ratio increases, the rate of genetic improvement across the herd accelerates proportionally and the economic value of that acceleration compounds across every production stage downstream.

This study compares Cervical Artificial Insemination, Post-Cervical Artificial Insemination, and Deep Intra-Uterine Insemination at each major stage of pork production:

Genetic Transfer Centers, Sow Farms, Wean-to-Finish Farms, and Slaughterhouses. The central question is whether these AI techniques differ meaningfully in their impact on genetics, production performance, and economics and if so, by how much and where in the production chain that value is generated.

The improvement in pork production efficiency observed in recent decades is the result of several converging biotechnological advances. Taking full advantage of genetic improvement programs depends on AI as the delivery mechanism for superior sperm to the site of fertilization. Major advances in genetics, nutrition, and disease control have each contributed to this trajectory (Gerrits, et al. 2005). This thesis focuses on the reproductive and genetic interface, specifically on whether the choice of AI technique is an underutilized lever for accelerating and capturing the economic value of genetic improvement across the entire production system.

1.1 Objectives

The objectives of this study are to analyze the economic advantages and disadvantages of different AI techniques at each stage of pig production, and to determine whether an economic incentive exists for the industry to adopt newer techniques beyond CAI and PCAI. The analysis is conducted at the Genetic Transfer Center, Sow Farm, Wean to Finish Farms and Slaughterhouse levels, using a Net Present Value framework to compare profitability across techniques and identify where in the production chain the economic case for adoption is strongest.

Each production stage differs from the others in structure, cost drivers, and economic output. The GTC produces and sells semen doses; the Sow Farm produces weaned piglets; the Wean-to-Finish Farm converts feed into live weight with measurable efficiency; and the Slaughterhouse converts live animals into carcass value and premium product. Because the goals and economic metrics differ at each stage, the analysis identifies not only whether a net economic advantage exists across the industry as a whole, but also which stages capture the most value and under what conditions that value is realized.

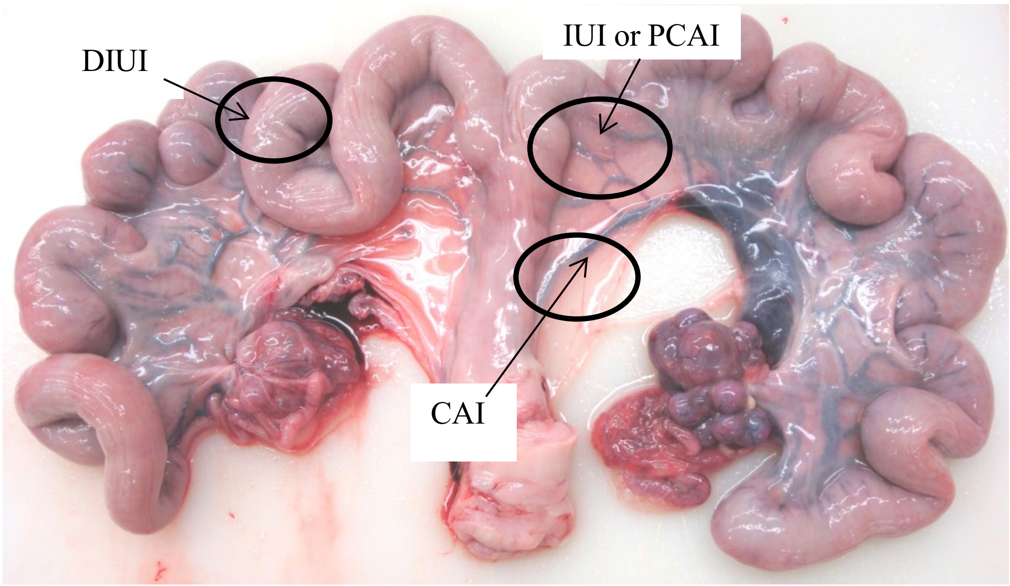
CHAPTER II: LITERATURE REVIEW

Artificial insemination was first demonstrated as viable for swine in 1948, when natural mating was the industry standard. Since then, rapid adoption of AI resulted from substantial improvements in AI technique and equipment, genetic evaluation programs, carcass merit measurement, and packer payment for carcass merit (Singleton 2001). AI adoption continues to evolve with ongoing research, and the techniques available today are substantially more efficient than those used even two decades ago.

AI in farm animals was initially adopted for biosecurity reasons, limiting the movement of live animals between farms. Producers subsequently recognized that an economic advantage could also be gained through improved fertility rates and accelerated genetic progress (Foote RH 1956). Recent research confirms that lowering the insemination dose is possible without a decrease in fertility, which increases the number of inseminations and the number of descendants from highly valuable sires; an outcome beneficial to AI centers and farmers alike (Rozeboom, Reicks and Wilson 2004) and this is the main objective of lowering the sperm concentration (Garcia-Vazquez F.A. 2019).

When considering AI techniques, the site of semen deposition within the female reproductive tract is among the most important factors determining the volume and sperm concentration necessary for normal reproductive performance (Hancock and Hovell 1961). The type of catheter used determines the depth of deposition, and with it, the AI technique, whether it is CAI, PCAI or DIUI. Each uses a different catheter design and protocol. The Figure 2.1 illustrates the deposition site depending on the insemination method on the female reproductive tract.

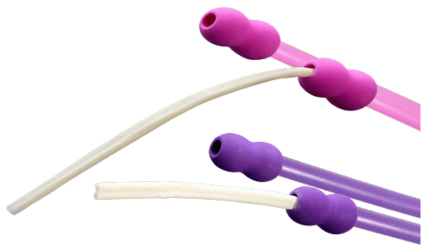
Figure 2.1 Deposition site of the semen depending on the insemination method



Source: Photo courtesy D. Mathew, University of Missouri-Columbia

It is known that by decreasing the number of spermatozoa required for successful insemination impacts the fixed costs of a dose of high added-value semen (e.g. sex-sorted sperm), promoting the use of these new sperm biotechnologies (Martinez, Vazquez, et al. 2005) as are PCAI and DIUI techniques. The new procedures deposit the spermatozoa in the uterine body (Post-Cervical Artificial Insemination or Intra-Uterine Insemination), or deep in the uterine horn (Deep Intra-Uterine Insemination), or in the oviduct (Laparoscopic Intra-Oviductal Insemination) (Vazquez, Roca, et al. 2008). In figure 2.2, there are presented several commercial catheters for PCAI.

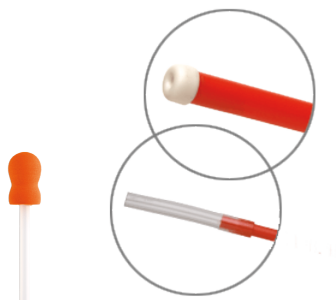
Figure 2.2 Most Used Commercial PCAI Catheters



Absolute sow (pink) and gilt (purple)

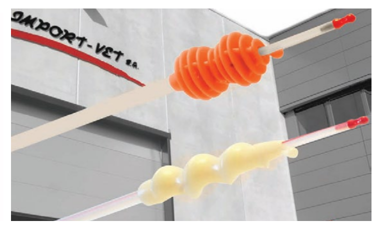
IMV-DeepGoldenPig

Minitube-Verona



Magapor- Magaplus

Cobiporc-Unic Systeme



Import-Vet- Soft&Quick

It was found in many trials that farrowing rates and litter size with PCAI with reduced numbers of sperm were comparable to CAI results (Pelland 2007). Taking advantage of these results there is a need to increase the efficiency of some genetically superior boars by increasing the number of doses per ejaculate, which can be achieved by decreasing the number of sperm per AI dose (Pelland 2007).

2.1 Production Science Details

2.1.1 Insemination Techniques

2.1.1.1 Cervical Artificial Insemination

Approximately 25 million inseminations are registered worldwide every year. In Europe up to 85-90% of swine inseminations annually are performed by AI (Vazquez, Roca, et al. 2008). The protocol recommends the deposition of a high number of spermatozoa (generally more than 2500 x 10^6 cells) in a large volume of extender (80-100mL), two- or three-times during estrus. This protocol limits the number of doses that can be prepared from one ejaculate to approximately 20- 25 (Vazquez, Roca, et al. 2008). Cervical Artificial Insemination involves depositing those sperm cells into the posterior region of the cervix (approximately 15 cm deep into the cervix) (Polge 1956).

With CAI the average annual semen production per boar is 1500 doses, able to inseminate approximately 700 sows. Unsatisfactory results have resulted when the insemination dose is reduced below 2500x10^6 spermatozoa (Alm, et al. 2006). CAI is the most widely used technique globally; it is straightforward to implement, requires no specialized equipment beyond standard catheters, and most farm personnel have extensive experience with it. These factors, combined with its established reliability, explain why CAI remains the dominant technique despite the efficiency advantages of newer approaches.

2.1.1.2 Post-Cervical or Intra-Uterine Insemination

Post-cervical AI was developed to reduce the number of sperm cells needed per AI, and yet still maintain adequate reproductive performance. Post-cervical AI utilizes a special catheter that contains an additional inner cannula to deposit the semen just past the cervix into the uterus (Fisher 2010). These techniques also tend to require more skill on the part of the breeder, as well as time to inseminate the sow (Belstra 2002) and this is necessary to obtain good results.

Current field standards for PCAI, based on data from 11 major international AI organizations, range from 1.1 to 2.2×10^9 spermatozoa per dose in a volume of approximately 40–60 mL (Waberski, et al. 2019). The practical standard most widely adopted in commercial operations is 1.5×10^9 spermatozoa in 45–50 mL (García-Vázquez, et al. 2019). Under these conditions, farrowing rates and litter sizes are comparable to those obtained with CAI at 3.0×10^9 cells in 80–100 mL, as confirmed by multiple trials.

A significant operational advantage of PCAI over CAI is the time required for insemination. It is confirmed that PCAI is approximately 2.5 times faster per sow than traditional CAI, meaning a single technician can service substantially more sows per unit of time (García-Vázquez, et al. 2019). This labor efficiency advantage is particularly relevant in the United States and other markets where farm labor is a significant cost and a constraint on production capacity.

Due to the anatomical characteristics of the gilt reproductive tract, this technique is generally not recommended for use in gilts. Advancing the inner cannula through the cervix is considerably more challenging in these younger females, and while it is technically possible, successful implementation requires a high level of skill, experience, and patience.

The PCAI devices are usually 15-20 cm longer than a conventional catheter, and the inner cannula is inserted through the lumen of the standard spirette, then advanced through the cervical canal to the uterine body. Various protocols have been described; most commonly, $1{,}000 \times 10^6$ spermatozoa in a volume of 30 mL (older recommendations) to $1{,}500 \times 10^6$ in 45–50 mL (current commercial standard) are used (García-Vázquez, et al. 2019).

In a study made by J.M. Vazquez et al in Spain (2008) comparing PCAI and CAI with different concentrations found that farrowing rates and litter sizes after post-cervical insemination with 3000, 2000 or 1000 x 10^6 spermatozoa were similar to those obtained with standard AI of 3000 or 2000 x 10^6 spermatozoa (Vazquez, Roca, et al. 2008). A study in 2005 demonstrated similar reproductive results when reducing PCAI concentration to 1.5×10^9 cells in 60 mL, with non-significant differences in conception rate (99.5% vs. 97.2%), farrowing rate (94.9% vs. 94.4%), and born alive (11.6 vs. 11.8) compared with CAI at 3.0×10^9 cells in 100 mL. (A. Mezalira, D. Dallanora and M. Bernardi, et al. 2005).

When using PCAI, proper farm management is essential for optimal results. Careful attention must be paid to catheter technique to minimize the risk of cervical or uterine damage, since semi-rigid extended catheters can damage reproductive tissues if used incorrectly (Vazquez, Roca, et al. 2008). Training of insemination staff is therefore a key prerequisite for successful adoption.

2.1.1.3 Deep Intrauterine Insemination

With deep intrauterine insemination semen is deposited directly into the uterine horns of the animal using a catheter similar to that used in post-cervical insemination (Fisher 2010). The principal obstacle to DIUI is the complex anatomy of the porcine genital tract, characterized by the length and coiled nature of the uterine horns. Devices used commercially have a length of approximately 1.80 m, with a 4 mm outer diameter and 1.80 mm inner tubing diameter. Deep uterine catheterization is performed after initial placement of a standard AI spirette to achieve cervical lock, followed by passage of the DIUI catheter through the spirette, cervical canal, uterine body, and into the uterine horn (Vazquez, Roca, et al. 2008).

Nonsurgical deep intrauterine insemination was first developed by Martinez et al (2001) as a practical alternative to surgical intra-uterine insemination, allowing substantially reduced sperm cell numbers. DIUI also permits the use of poorer-quality sperm such as cells damaged by cryopreservation because deposition closer to the site of fertilization reduces the distance cells must travel and compensates for reduced motility (Vazquez, et al. 2005). DIUI also minimizes backflow by using a smaller volume, causing spermatozoa to reach the site of fertilization more rapidly (Bennemann, et al. 2004).

Martínez et al. (2002) compared DIUI at single inseminations of 15.0, 5.0, 2.5, or 1.0×10^7 cells/dose to CAI at two inseminations of 3.0×10^9 cells/dose. No difference in farrowing rates was observed between CAI and DIUI at 15.0 or 5.0×10^7 cells/dose. However, significant decreases in farrowing rate were observed at 2.5×10^7 (46.7%) and 1.0×10^7 (39.1%) cells, indicating a minimum threshold concentration for DIU (Martinez, Vazquez, et al., Minimum number of spermatozoa required for normal fertility after deep intrauterine insemination in non-sedated sows 2002).

DIUI is particularly relevant as a delivery method for biotechnologies including frozen or sex-sorted semen. Globally, however, frozen semen currently represents less than 1% of all AI doses used commercially (Waberski, et al. 2019). The commercial application of DIUI therefore remains largely in specialized contexts to use of frozen semen in bio secure environments, specific genetic importation situations (e.g., Australia, Guatemala), and potential future applications with sex-sorted sperm or genetically modified animals, including the PRRS-resistant pigs currently in development.

2.1.2 Comparison of AI Techniques

Billions of spermatozoa are deposited intra-cervical during mating or AI, however, only a very small proportion of the spermatozoa reach the sperm reservoir (Mburu, et al. 1996). As documented by Vázquez et al. (2005), approximately 70% of the semen volume and 25–45% of the sperm cells are lost as they flow back out of the reproductive tract following CAI. PCAI reduces this backflow to approximately 15%, primarily by depositing semen directly into the uterine body past the site of greatest loss (García-Vázquez, et al. 2019). This biological efficiency gain is what makes reduced sperm concentrations feasible without compromising farrowing rate or litter size. Table 2.1 shows AI as the control group compared with the new techniques.

Table 2.1 Fertility of Sows Following Conventional A.I., Intra-Uterine Insemination or Deep Intra-Uterine Insemination

Study	Site of semen deposition	Sperm/ Dose (x 10^9)	Vol/Dose (mL)	Doses/Sow	Number of Sows	CR (%)	FR (%)	Total Born	Born Alive
Watson and Behan, 2002	AI	3.0	80	2	540	91.3	91.1	12.5	10.9
	IUI	3.0	80	2	540	91.8	90.5	12.3	11.0
	AI	2.0	80	2	540	91.1	91.8	12.6	10.9
	IUI	2.0	80	2	540	92.6	92.5	12.3	10.8
	AI	1.0	80	2	540	66.2	65.8	10.3	9.0
	IUI	1.0	80	2	540	88.7	86.9	12.1	10.9
Rozeboom et al., 2004	IUI	0.5	85	2	106	86.6	78.0	9.4	8.6
	IUI	1.0	85	2	106	88.2	87.0	10.0	9.3
	IUI	4.0	85	2	106	96.5	94.4	11.0	10.5
	AI	4.0	85	2	104	92.1	88.2	11.6	10.8
Roca et al., 2003	DIUI (frozen) synch	1.0	5	1	49	79.59	77.55	9.31	-
	DIUI (fresh) synch	0.15	5	1	29	82.76	82.76	9.96	-
	AI (frozen) not synch	6.0	100	1	33	78.79	75.76	9.60	-
	DIUI (frozen) not synch	1.0	5	2	40	72.50	70.00	9.25	-
	DIUI (fresh) not synch	0.15	5	2	38	84.21	84.21	9.88	-
Benneman et al., 2004	IUI	1.0	60	1	21	82.1	69.8	-	-
	IUI	2.0	60	1	27	96.5	64.7	-	-
Martinez et al., 2001	AI	3.0	100	2	147	86.4	83.0	10.0	9.4
	DIUI	0.15	5	1	117	86.3	82.9	9.7	9.3
	DIUI	0.05	5	1	126	77.8	76.2	9.4	8.9
	DIUI	0.025	5	1	60	51.7	46.7	9.3	8.8
	DIUI	0.010	5	1	69	39.1	39.1	9.4	9.0
Gal 2002	AI	3	75	>2	141	-	86.2	-	9.9
	IUI	0.6	30+18	>2	145	-	85.1	-	10.1

CR= Conception Rate: the percentage of sows pregnant at a 28-day pregnancy check

FR= Farrowing Rate: the percentage of sows that went onto to farrow

The studies summarized above demonstrate that PCAI and DIUI allow for meaningful reductions in sperm concentration and insemination volume while preserving reproductive efficiency comparable to CAI. Conversely, attempts to reduce CAI dose parameters beyond established limits result in compromised fertility performance. Accordingly, determining the minimum effective dose for each technique remains a central research question. Knox (2025) confirms that while fertility is equivalent between CAI and IUI/PCAI, IUI takes far less time and reduces sperm leakage, two complementary advantages that together justify the higher per-catheter cost at the sow farm level. The economic case for PCAI adoption is therefore built on three simultaneous effects: (1) reduced semen cost per dose enabling more doses per ejaculate at the GTC level, (2) labor savings from faster insemination at the sow farm level, and (3) accelerated genetic dissemination improving downstream production traits at the wean-to-finish and slaughter levels. Evidence from Dallanora (2009) provides valuable insight, showing that PCAI maintained equivalent conception and farrowing rates to CAI even when the concentration was lowered to 1.5 $x10^9$ sperm cells in 60mL, as presented in Table 2.2.

Table 2.2 Concentration reduction with PCAI

	PCAI, 1.5B, 60ml	**AI 3B, 100ml**	***P***
Conception Rate, %	99.5	97.2	NS
Farrowing Rate, %	94.9	94.4	NS
Born Alive	11.6	11.8	NS
Back flow, %	75.4	62.7	<0.05

Source: Dallanora et al.(2009)

The following table summarizes the key technical differences between natural mating, traditional CAI, and PCAI, including the critical operational advantage of insemination time:

Table 2.3 Comparison of volume, concentration, deposition site and length of time between insemination techniques

	Mating with a boar	Traditional AI	Post-Cervical AI	DIUI
Volume fluid, ml	250-400	70-80	15-40	5-10
# sperm cells, billions	60-80	2-3	0.5-1.5	0.05-0.1
Location of sperm deposition	Cervix	Cervix	Uterine body	Uterine horn
Length of time	5-10 minutes	3-5 minutes	10-15 seconds	2-5min*
Boar:Sow ratio	1:25	1:150	1:450	1:3,000

An important management consideration when using PCAI with reduced sperm doses is the interaction between dose reduction and insemination frequency. A commercial-scale trial in Thailand (Pearodwong, et al. 2020) evaluated fixed-time single AI protocols in a 2,500-sow herd across cool and hot seasons. The study found that PCAI at the reduced concentration of 1.5×10^9 sperm combined with a single fixed-time insemination resulted in a significant reduction in total born (11.7 vs. 12.9, $P = 0.013$) compared with conventional double insemination. In contrast, CAI at the conventional 3.0×10^9 dose with single fixed-time AI showed no litter size reduction (12.7 vs. 12.5, $P = 0.772$). Farrowing rates were not significantly different between protocols (92.8% conventional vs. 88.1% fixed time), demonstrating that farrowing rate is robust across techniques, but total litter size is sensitive when two efficiency reductions are stacked simultaneously.

The practical implication for producers considering PCAI is clear: reducing sperm concentration is safe and economically justified when using standard two- or three-insemination protocols per estrus. However, combining PCAI reduced-dose protocols with single fixed-time insemination creates additive risk to litter size, and should not be implemented without careful evaluation of genetic and economic trade-offs. In production environments subject to heat stress as is the case of Mexico, tropical Latin America, Southeast Asia; a seasonal effect on litter size was also observed in the PCAI group (born alive 10.9 in hot season), suggesting that risk management for these markets should account for seasonal variation in NPV projections.

PCAI and DIUI are not recommended for routine commercial use in gilts due to the reduced flexibility of the nulliparous cervical tissue, which increases the risk of tissue damage and makes inner cannula passage more difficult. However, field evidence from Argentina (Luchetti, Renoulin and Lombardo 2016) demonstrates feasibility in nulliparous females under experienced operator conditions, with the cannula advancing 3–6 cm through the gilt cervix rather than the greater depth achieved in multiparous sows. This anatomical limitation is the primary reason commercial models for PCAI economics focus on multiparous sow populations. With special training and appropriate equipment, gilt PCAI is possible but requires careful implementation.

In terms of production efficiency, these new AI techniques enable a significant increase in genetic gain by reducing the cost per dose and maximizing the use of genetically superior males. With PCAI, one boar can attend approximately 450 females, compared with 100–150 under CAI (Eduardo Paulino da Costa 2011), representing a threefold increase in genetic dissemination. DIUI can extend this to approximately 3,000 females per boar. This concentrated impact of superior genetics on a larger female population accelerates genetic improvement in economically important traits across the entire production system.

2.1.3 Anatomical Basis for Technique Differences

The differential performance of PCAI and DIUI relative to CAI across female parity categories is grounded in the anatomy of the porcine cervix and uterus. García-Vázquez et al. (2019) quantified cervical morphology in nulliparous versus multiparous sows and documented significant anatomical differences that explain both the efficiency advantages of PCAI and its commercial restriction to multiparous females.

Multiparous sows have significantly longer cervical canals (25.9 cm vs. 21.6 cm in nulliparous females) and a greater total cannula path length (56.2 cm vs. 50.3 cm). The cranial cervix of nulliparous females exhibits higher ridge density, smaller lumen diameter, and less connective tissue, creating a mechanical barrier that increases resistance to catheter passage. In contrast, multiparous females have more connective tissue and less muscle fiber in the uterine portion of the reproductive tract, providing increased distensibility that facilitates PCAI cannula advancement and accounts for the consistently high PCAI success rates (>95%) observed in commercial multiparous sow populations. These anatomical differences are the mechanistic basis for the producer guidance that restricts routine commercial PCAI to multiparous sows.

2.1.4 Genetic Improvement

Pork producers globally must exploit the power of genetic improvement programs to improve production efficiency. While most commercial producers understand the returns associated with improved management, the majority do not fully realize the economic impact of systematic genetic improvement (Schinckel n.d.). This is partly due to the absence of economic analyses and yield performance data that demonstrate improvement on individual farms.

Genetic selection is the foundation of genetic improvement, and there are multiple approaches to selection. Two key terms are relevant: Estimated Breeding Value (EBV), the estimated genetic merit of an individual expressed as a deviation from population average; and Expected Progeny Difference (EPD), equal to one-half of an animal's EBV, which estimates the expected performance change in progeny if the animal is used as a parent (Thomas E. Long, Estimating Genetic Merit 2003). These estimates are made using data from relatives and offspring to improve accuracy.

Index Selection combines the net values of all traits in the selection criteria into a single index value, using heritability, trait correlations, and economic values of each trait. Index selection has advantages over independent culling levels in that all traits are improved simultaneously, and differential economic emphasis can be placed on each trait (T.S. Stewart 2006). This study therefore uses index values in economic models.

The major entities with a stake in genetic improvement include farmers, breeders, food processors, consumers, and governments. Although farmers are the primary consumers of genetic improvement services, the primary beneficiaries are ultimately consumers through lower meat prices and improved product quality (Weller 1994). This underscores the value of measuring benefits across the whole industry value chain.

As an example of the magnitude of historical genetic progress: over the past two decades in the U.S., feed efficiency ratio per pound of weight gain improved from 4.25 to 3.75, lean meat in the carcass increased from 42 to 51 percent, and pounds of carcass produced per sow per year nearly doubled from 1,625 to 3,095 pounds (Gerrits, et al. 2005). PCAI and DIUI accelerate this trajectory by enabling a single superior boar to disseminate his genetics to a far larger population of females.

An additional dimension of genetic dissemination gaining industry relevance is PRRS (Porcine Reproductive and Respiratory Syndrome) resistance. CRISPR/Cas9-edited PRRS-resistant animals have been developed and their potential commercial introduction producing animals resistant to one of the most economically devastating disease threats in pork production, will require wide genetic dissemination across industry populations (Waberski, et al. 2019) (Whitworth, et al. 2016). Given that such resistance traits would need to spread rapidly through large commercial populations, PCAI and DIUI could be an essential tool for this genetic dissemination and transition. The reduced semen concentration per dose enables production of significantly more doses per ejaculate from the limited number of these genetically modified animals, making PCAI not just economically attractive but potentially necessary for implementation of disease-resistance genetics at scale.

Biotechnologies are essential for genetic dissemination, and AI has been a key enabler. In Europe, AI has had a major impact on pig genetic improvement over the past 35 years, and more recently in the USA (Gerrits, et al. 2005). The overall production efficiency of the breeding herd is highly dependent on the reproductive capacity of boars and their genetic merit (Dyck 2012). AI plays an important role in animal breeding by increasing the utilization of genetically superior sires, with objectives of broadly distributing desirable genes, controlling disease, and increasing economic profits (Oh 2003).

2.2 Economic Literature

2.2.1. Global Pig Inventory Overview

Global and regional pig inventories have continued to evolve substantially. The data presented below reflect the most current figures available across the major producing regions, providing an updated economic and operational context for evaluating artificial insemination technologies in the swine industry.

Global pig production has increased by 140% since the 1960s, driven by population growth and improving socioeconomic conditions worldwide. As of 2021–2023, there are approximately 780–900 million pigs raised globally, approaching 1 billion head (Kim, et al. 2024) (FAO, FAOStat analystical brief 96. Agricultural production statistics 2010-2023 2023). Asia remains the dominant region, holding 57% of the world's pigs, followed by Europe (19%), Latin America (9.6%), North America (9.1%), and Africa (4.4%) (Kim, et al. 2024).

China is the single largest pig-producing country, with an estimated 452.6 million pigs and 55.0 million metric tons of pork production in 2023: representing 46–48% of global output. The European Union ranks second with 134.3 million pigs and 22.9 million metric tons of pork production, followed by the United States at 74.4 million pigs and 12.5 million metric tons. Brazil, Russia, Vietnam, Canada, Mexico, Korea, and Japan complete the top 10, which collectively account for 81% of the global pig population and an estimated 94% of all pork produced worldwide (FAO, FAOStat analystical brief 96. Agricultural production statistics 2010-2023 2023) (Kim, et al. 2024).

Table 2.4 Top 10 Countries: Pig Inventory and Pork Production (2023)

Country	Pork (million t)	Pigs (million hd)	Share of Global production
China	55.0	452.6	~46%
EU	22.9	134.3	~20%
USA	12.5	74.4	~11%
Brazil	4.4	34.3	~4%
Russia	3.8	27.1	~3%
Vietnam	2.8	23.5	~2%
Canada	2.1	13.9	~2%
Mexico	1.6	12.3	~1%
Korea	1.4	11.1	~1%
Japan	1.3	8.9	~1%

Sources: Kim et al. (2024); Pig Progress (2023); USDA/FAS (2024)

A critical finding from recent literature is that pig inventory does not directly translate to proportional pork output due to significant differences in production efficiency. The EU produces 40% more pork per pig and the US produces 38% more pork per pig compared to China (Kim, et al. 2024). This efficiency gap is explained primarily by differences in market weight; China markets pigs at approximately 105 kg bodyweight, while the EU and US market at approximately 130 kg; as well as differences in feed composition, genetics, management intensity, mortality, and morbidity rates.

This efficiency differential is directly relevant to the economic analysis of AI techniques. Higher-index genetics, disseminated through more efficient AI protocols (PCAI and DIUI), can accelerate progress in feed conversion ratio, average daily gain, and carcass yield; all of which contribute to closing efficiency gaps among producing regions and within individual farm operations.

2.2.2. Sow Inventory and Productivity

In the United States, the total pig inventory stood at approximately 74.4 million head in 2023 (FAO, FAOStat analystical brief 96. Agricultural production statistics 2010-2023 2023), compared with 65.9 million head reported in 2014 (USDA, Livestock & Poultry. World Markets and Trade 2014). The US breeding sow inventory is currently estimated at 6.09 million head as of 2024, a slight decrease of 0.2% year-over-year, reflecting ongoing industry consolidation and efficiency-driven herd optimization (USDA, Livestock and poultry: World markets and trade 2025). The US pork industry is dominated by 36 systems for approximately two-thirds of commercial pork production, with 83% of sow ownership concentrated in operations exceeding 10,000 sows (R. Knox 2025).

In Canada, the breeding sow inventory for 2024 is estimated at 1.21 million head, a reduction of 1.6% from the prior year, consistent with industry rationalization trends observed across North America (USDA, Livestock and poultry: World markets and trade 2025). The Canadian total inventory of approximately 13.9 million head in 2023 represents continued stable production capacity.

Latin America as a whole holds approximately 20 million pig farms, with 70% of regional sow production concentrated in Brazil and Mexico; Brazil showed significant sow inventory expansion in 2024 (R. Knox 2025) (USDA, Foreign Agricultural Service 2024), driven by export market opportunities and competitive exchange rates. Mexico's pig inventory reached approximately 12.3 million head in 2023, with a breeding inventory estimated at approximately 950,000 sows in commercial operations (Kim, et al. 2024).

Sow productivity has continued its sustained long-term improvement trajectory. In the EU, super-prolific sow lines have demonstrated litter sizes of 18–20 pigs born per litter at specific genotypes and parities. In the US and other major producing countries, average litter sizes currently range between 14 and 16 pigs born alive, with annual upward trends persisting (R. Knox 2025). This compares favorably with 9.96 pigs weaned per litter reported in 2014.

Modern sows average 14–16 functional teats, and selection for teat number is increasingly incorporated into genetic programs to support larger litter sizes with adequate milk availability. However, the increase in litter size has been consistently associated with lower individual birthweight, more pigs born under 1 kg, and higher stillbirth rates, creating an ongoing management and genetic challenge for the industry (R. Knox 2025). Birthweight directly affects pig vitality, survival, growth performance, and even lifetime reproductive fertility of replacement gilts.

The biological ceiling for litter size is governed by ovulation rate, fertilization rate (estimated at approximately 95%), and embryo survival (ranging from 50–90%) through day 28 of gestation. Early embryo loss by day 10 accounts for approximately 20% of fertilized ova, while late embryo loss after day 25 — driven by competition for uterine space among large litters — contributes an additional 15% reduction (R. Knox 2025). As litter sizes approach 18–20 pigs, the productive capacity of the uterus becomes a limiting factor, and nutritional, management, and genetic interventions during early gestation become increasingly critical.

Table 2.5 Sow Productivity Benchmarks: 2014 vs. 2024

Metric	2014	2024
US total pig inventory	65.9M hd	74.4M hd
US sow inventory	5.76M hd	6.09M hd
Canada sow inventory	1.22M hd	1.21M hd
Mexico sow inventory	1.1M hd	0.95M hd
US pigs weaned/litter	9.96	11.92
Global pig population	780M	780-900M
Global pork production	94M metric tons	125M metric tons

Sources: Kim et al. (2024); Knox (2025); FAOSTAT (2023); USDA/FAS (2024); National Pork Board (2011); USDA (2014); INEGI (2007); Production Analysis for U.S. Pork Industry: 2020-2024.

A defining structural trend across all major producing regions is the progressive consolidation of sow ownership into fewer, larger operations. In the US, the top 25 pig producers owned approximately 4.1 million sows in 2020; representing 65% of the total US sow population, up from just 1.3 million sows held by the top 25 producers in 1995 (Kim, et al. 2024). Globally, the top 10 pig producers own 11 million sows (17% of the world’s total sow population), and the top 40 global producers collectively account for 26% of all sows worldwide. The top 10 global producers are concentrated in China (6 companies), the US (2), Thailand (1), and Brazil (1) (Kim, et al. 2024).

This consolidation trend is directly relevant to the adoption of advanced AI technologies. Larger, integrated operations have greater capacity to implement standardized PCAI and DIUI protocols, justify capital investment in specialized catheters and semen processing infrastructure, and realize economies of scale in genetic dissemination. Knox (2025) confirms that 40 farms from only 9 countries produce more than 25% of the world's pork, and that Mega companies (≥100,000 sows) and Large systems (≥10,000 sows) are the primary drivers of commercial production growth in China, the EU, and the US.

The breeding herd continues to face significant disease-related challenges that directly affect sow inventory and productivity. African Swine Fever (ASF) has been the most impactful global disease event of the past decade, devastating pig populations in China and Southeast Asia. In China, ASF resulted in a 28% reduction in pig population between 2018 and 2019, with domestic pork production falling by 11 million metric tons in a single year (FAO, FAOStat analystical brief 96. Agricultural production statistics 2010-2023 2023). Vietnam experienced a similar ASF-driven decline around 2018, from which it is still recovering. Germany has seen a structural decline in pig numbers since 2014 driven by environmental regulation and welfare compliance costs, rather than disease (Kim, et al. 2024).

In North America, PRRS (Porcine Reproductive and Respiratory Syndrome) remains the single greatest endemic disease challenge for breeding herds, causing nursing pig mortality, sow reproductive failures, reduced milk production, and elevated sow mortality. PRRS adds significant costs to production, requiring biosecurity investment, strategic depopulation, vaccination programs, and enhanced air filtration systems at boar studs. The COVID-19 pandemic additionally exposed critical vulnerabilities in breeding farm labor supply chains, reinforcing the value of management technologies that reduce labor requirements per sow; including PCAI, which reduces insemination time from 3–5 minutes per sow (CAI) to approximately 10–15 seconds (R. Knox 2025).

2.2.3 Boar Inventory and Productivity

Boars are the critical leverage point in genetic dissemination because of the structure of modern pork production systems. In the current commercial industry, boars are housed in specialized facilities called Genetic Transfer Centers (GTCs) or Boar Studs, operated either as standalone businesses or as integrated components of genetic company supply chains. The semen productivity of boars at the GTC depends on facility design, biosecurity and health status, collection frequency, semen processing equipment, and quality control systems. Producing a high-quality semen dose at a controlled and competitive cost is the core operational objective of every GTC.

As the industry moves toward reduced sperm concentration and volume per dose under PCAI and DIUI protocols, GTCs face increasing demands on quality standardization. This is the case in Brazil, where (Janaina Colecha Rocha 2023), in an audit of 11 Brazilian boar studs across 24 months covering 1,650 boars, confirmed that approximately 74% of doses produced were for PCAI (45 mL format) containing an average of 1.9 billion sperm cells, while CAI doses averaged 80 mL with 3.3 billion sperm cells. Maintaining minimum recommended sperm concentration thresholds (≥60 million sperm/mL during storage) is critical to prevent motility decline over the 3–5-day storage period at 17°C..

Knox (2025) adds an important biosecurity dimension: PRRS virus represents the single greatest continuous threat to boar stud integrity, driving investment in HEPA air filtration systems, positive-pressure ventilation, and strict personnel and vehicle biosecurity protocols at commercial GTCs. Disease entry can impact dose fertility and farm-level reproductive performance for weeks, with downstream financial losses extending across the entire customer sow farm network.

About the semen production parameters, the first systematic analysis of US boar stud production benchmarks was conducted by (Stephanie C. Rutten, Robert B. Morrison and Darwin Reicks 2000), analyzing collection records of 1,646 boars across seven United States studs. Boars averaged 31.4 usable doses per boar space per week, with an average collection frequency of 1.1 times per week. Stud-level averages were slightly higher at 35.5 usable doses per boar space per week with 1.2 collections per week. Four of the seven studs used 3×10^9 usable sperm cells per dose as the standard; the remaining three studs varied dose concentration by boar, ranging from 2.5×10^9 to 5.0×10^9 cells. These benchmarks from Rutten et al. (2000) underpin the production parameters subsequently incorporated into industry standard and serve as the peer-reviewed foundation for the production metrics used in this thesis's NPV model.

Rutten et al. (2000) further established the economic framework for GTC management decisions through a partial budget model assessing collection interval impact. Their analysis demonstrated that the optimal collection interval depends on the management priority: a least-cost approach favors less frequent collection to minimize labor; a maximum-profit approach favors the highest dose output; and a best-return-on-investment approach favors collecting every 3–4 days (twice per week). Labor accounted for a substantial portion of stud budgets in their model, a cost structure that remains relevant to GTC economic analysis today. The sale price per dose in their 2000 model was $6.00, a figure that has likely increased substantially with general inflation and the shift toward PCAI-quality dose standards.

Table 2.6 Boar Stud Production Parameters (Stephanie C. Rutten, Robert B. Morrison and Darwin Reicks 2000)

Parameter	Boar Average (n=1,646)	Stud Average (n=7)
Usable doses / boar space / week	31.4	35.5
Collections / week (frequency)	1.1	1.2
Usable doses / collection / boar	27.4 ± 13.6	40.5 ± 5.5
Wasted collections (%)	5.0%	3.8% ± 3.0%
Usable sperm / collection (%)	92.3% ± 1.1%	91.7% ± 1.4%
Standard dose concentration	3.0 × 10^9 cells (4 of 7 studs)	Range: 2.5–5.0 × 10^9
Best ROI collection interval	3–4 days (2×/week)	Varies by management goal
Seasonal peak / trough	Fall/Winter (highest)	Spring/Summer (lowest)

Source: Rutten, Morrison & Reicks (2000). Swine Health and Production 8(1):11–14. Data from 1,646 boars in 7 US commercial and on-farm studs. Seasonal differences in usable doses per collection ($P<0.001$), usable sperm per collection ($P<0.01$), and usable collections ($P<0.05$) were statistically significant.

A key finding from Rutten et al. (2000) with direct relevance to this thesis is that increasing collection frequency is the primary driver of annual dose output per boar, outweighing boar age effects on individual ejaculate yield. Their data showed that boars collected daily produced approximately 15,875 doses annually, while those collected every 3 days produced 3,107 doses, a dramatic difference driven by collection frequency rather than biology alone. This operational insight reinforces why GTC management decisions about collection scheduling are as economically important as boar genetic selection decisions.

A typical boar in a North American GTC produces approximately 1,100–1,200 doses of semen per year at standard CAI protocol (3.0 × 10^9 cells per dose), at a collection frequency of 1.1–1.2 times per working boar per week (PIC 2006). The Brazilian boar stud audit by Rodrigues et al. (2024) reported a higher average of 112.9 doses per boar per month, reflecting the shift in that market toward PCAI dose standards (smaller volume, lower concentration) which yield more doses per ejaculate. Under PCAI protocols at 1.5 × 10^9 cells per dose, the number of doses per ejaculate increases to approximately 60–80, compared with 40–50 for standard CAI doses; a 50–60% increase in yield per ejaculate (Waberski, et al. 2019).

Boar age has an important but nuanced effect on semen production. Rutten et al. (2000) found a low but statistically significant positive correlation between usable doses per collection and boar age ($r = 0.077$, $P<0.001$), with less production variability observed among boars over 24 months of age, suggesting that mature boars are more consistent, if not always higher-volume, producers. The established benchmark data on the age-production relationship are presented in Table 2.9b below.

Table 2.7 Effect of age of boar on semen characteristics when collected three times per week

Age (mo)	8-12	13-15.5	16-18
Total volume (mL)	290	381	297
Sperm concentration $x10^6$/mL	117	169	202
Total sperm ($x10^9$)	18.8	33.5	35.4
Daily sperm output ($x10^9$)	8.1	14.3	15.2

Source: Wayne L. Singleton

In the world, there are many Boar Studs sizes and there are a lot of variations between them. But taking a look at the inventory of boars used per country we can see the scope of the industry and the production level of each. We can see in Table 2.9, the boar inventory per country and the total doses produced per year. In the US the inventory is 27,000 boars approximately with a total of 34,000 million of doses per year.

Rutten et al. (2000) also found a statistically significant positive correlation between percent usable sperm per collection and boar age ($r = 0.810$, $P<0.001$), suggesting that semen quality; as measured by usable sperm percentage, improves substantially with boar maturity. The practical implication is that younger boars, while carrying superior genetics, produce lower-volume, more variable ejaculates during their early productive period. This biological reality is a key factor in GTC boar inventory sizing: studs cannot simply replace all boars with the youngest available genetics without accepting a temporary reduction in dose output and quality consistency.

Understanding boar culling rates and longevity is essential for accurate GTC cost modeling, since boar depreciation (the cost of purchasing, acclimating, and replacing boars) is one of the largest fixed cost components at the GTC level. (Yuzo Koketsu 2008) Koketsu and Sasaki conducted the first systematic benchmarking study of boar removal in commercial herds, analyzing 2,474 boar records from 108 commercial breeding herds using PigCHAMP data. Their results provide industry benchmarks that are directly applicable to GTC replacement rate planning and NPV model assumptions.

Mean boar life day (BLD, from birth to removal) was 984 ± 9.5 days, and mean boar herd life day (BHLD, from herd entry to removal) was 781 ± 8.4 days — equivalent to approximately 2.7 years of total life and approximately 2.1 years of productive herd life. The annualized culling rate was 0.411 boars per 365 BHLD, and the annualized mortality rate was 0.035 boars per 365 BHLD. Combining these, the total annualized removal rate is approximately 0.468 boars per boar per year, implying an average annual replacement rate of approximately 40–50% of the boar population.

Knox (2025) adds a forward-looking dimension to boar replacement strategy: as single-sire AI technology and ultra-low sperm dose protocols develop, the individual fertility of boars will become an even more critical selection criterion. Currently in many GTC systems, ejaculates are pooled from 4–6 boars of similar genetic background (Knox, 2008), masking individual boar fertility variation. Future precision systems may require single-sire identification for disease traceability and individual fertility ranking, changing the cost and management structure of the GTC replacement program.

Table 2.8 AI and PCAI adoption in Major Pork-Producing Countries

Country	Sows (M)	AI %	PCAI % of AI	Boars (approx.)	Doses/Yr (millions)	Primary Source
China	44.0	10–15	<5	n/a	24,000	Waberski et al. (2019)
USA	6.1	~90	~40	~27,000	34,000	Knox (2025); Waberski (2019)
EU (total)	11.0	~90	Varies*	~65,000	~80,000	Knox (2025); EC (2024)
Spain	2.2	95	~60	7,500	12,500	Waberski et al. (2019)
Germany	2.0	~95	~20	6,611	12,470	Waberski et al. (2019)
Brazil	2.4–2.7	95	>80	n/a	12,000+	Knox (2025); Rodrigues (2024)
Canada	1.21	80	~25	n/a	5,700	USDA/FAS (2024)
France	1.2	95	<20	3,709	5,630	Waberski et al. (2019)
Mexico	0.95	90	~25	n/a	5,500	Waberski et al. (2019)
Denmark	1.1	95–98	~15	3,150	5,400	Waberski et al. (2019)

*EU PCAI adoption varies by country: ~60% in Spain, ~20% in Germany, <20% in France and Denmark. Sources: Waberski et al. (2019); Knox (2025); Rodrigues et al. (2024); USDA/FAS (2024); European Commission (2024). AI dose quality standards compiled by Waberski et al. (2019) from 11 international breeding organizations: CAI standard = 1.3–4.0 × 10^9 sperm/dose; PCAI standard = 1.1–2.2 × 10^9 sperm/dose.

The global trend toward PCAI adoption is clear and accelerating. Knox (2025) confirms US PCAI adoption at approximately 40% substantially higher than the ~10% figure from earlier estimates in the original thesis. Brazil exceeds 80% adoption, driven by cost-saving rationale, favorable regulation, and the well-documented high semen quality standards in Brazilian commercial studs (Rodrigues et al., 2024). Waberski et al. (2019) formalized these reduced-dose PCAI standards at the international level, confirming commercial best practice acceptance.

2.2.4 GTC Production Costs

Costs at the GTC level represent the first link in the pork production chain and are foundational to the NPV model constructed in this thesis. GTC production costs vary significantly with stud size due to economies of scale in labor, equipment utilization, and semen processing infrastructure.

The economic framework for GTC cost analysis was established by Rutten, Morrison, and Reicks (2000), who developed a partial budget model that disaggregates GTC costs into three categories: (1) fixed costs per boar space (facility, feed, utilities, miscellaneous health); (2) costs per collection (labor, laboratory supplies); and (3) costs per dose (extender, packaging, post-evaluation labor). Using 2000 price levels, their model showed a sale price of $6.00 per dose, with fixed facility costs of $6.30 per boar space per week and collection labor of $6.30 per collection. The most important cost management insight from their model is that collection frequency is the primary dial for managing profitability: a 3–4 day interval (twice weekly) maximized return on investment in their analysis.

Table 2.9 GTC Cost Benchmarks by Category (Multiple Sources)

Cost Category	Rutten et al. (2000)	PIC (2006)
Dose sale price	$6.00 / dose	Not specified
Facility fixed cost	$6.30 / boar space / week	$2,000–$2,200 / boar space (capital)
Collection labor cost	$6.30 / collection	$670–$700 / boar space / year
Extender + packaging (dose cost)	$0.50 / dose	Not itemized
Dose production cost (>200 boars)	Not specified	$2.00–$2.25 / dose
Dose production cost (100 boars)	Not specified	$3.25–$3.50 / dose
Site preparation cost	Not specified	$1,000–$1,200 / boar space
Lab equipment per 100-boar increment	Not specified	$25,000–$30,000
Automated packaging threshold	Not specified	≥200 boars
Lab technician: boar ratio	Not specified	1:125 to 1:200
Optimal collection interval (best ROI)	3–4 days (2×/week)	Not specified
Poor water supply extra cost	Not specified	$11,000–$12,000

Sources: Rutten, Morrison & Reicks (2000); PIC (2006); Compeer Financial (2024); Rodrigues et al. (2024)

Implementing PCAI and DIUI at the GTC level requires investment in more sophisticated semen processing infrastructure than standard CAI. Computer-assisted sperm analysis (CASA) for motility and morphology assessment is essential when reducing sperm concentration, to guarantee reproductive performance at the sow farm level (R. Knox 2025). Rodrigues et al. (2024) confirmed that bacterial contamination risk increases significantly when boars are inadequately housed or doses are processed under elevated temperatures, underscoring the value of environmental controls and HACCP-based quality systems.

It is common practice in North American boar studs to pool semen from 4–6 genetically similar boars, creating operational efficiencies and reducing the impact of individual boar fertility variation on dose-to-dose consistency (R. D. Knox 2008). However, Knox (2025) notes that regulatory environments requiring single-sire identification for disease traceability would preclude pooling, affecting GTC workflow and labeling costs. This trade-off between operational efficiency and traceability requirements is an important consideration for GTCs operating in or supplying different regulatory jurisdictions.

With the reduction in sperm concentration per dose under PCAI protocols, fewer boars of higher average genetic index are required to supply the same sow population. The economic value of this genetic upgrading is quantified using the index approach: value per pig = (improvement in genetic index) × (value per index point) (A. Minton 2013). This connection between GTC boar selection strategy and downstream production value is the central economic argument of this thesis and is quantified in the NPV model in Chapter IV.

Table 2.10 Dose Yield and Cost Logic: CAI vs PCAI at the GTC Level

Parameter	CAI Standard	PCAI Standard
Sperm cells per dose	3.0×10^9	1.5×10^9
Volume per dose (mL)	80–100 mL	45–50 mL
Doses per ejaculate (approx.)	40–50	60–80
Dose yield increase vs. CAI	Baseline	+50–60%
Annual doses per boar	~1,100–1,200	~1,650–1,920 (estimated)
Annual doses per boar space per week	31.4 (Rutten et al., 2000)	~47–50 (estimated, 2×/week collection)
Boar: Sow ratio achievable	1:150	1:450
Replacement rate (annualized)	~40–50% (Koketsu & Sasaki, 2009)	Same (biology unchanged)
Quality control requirement	Standard CASA + morphology	Enhanced CASA + strict QC

PCAI annual dose estimate derived by applying the 50–60% ejaculate yield increase (Waberski et al., 2019) to the CAI baseline of 1,100–1,200 doses/boar/year (Rutten et al., 2000; PIC, 2006). Replacement rate from Koketsu & Sasaki (2009) annualized removal rate of 0.468. Sources: Rutten et al. (2000); PIC (2006); Waberski et al. (2019); Rodrigues et al. (2024); Knox (2025); Koketsu & Sasaki (2009).

The economic case at the GTC level integrates all three dimensions simultaneously: (1) more doses per ejaculate reduces per-dose variable cost; (2) fewer boars required to supply the same sow population reduces fixed capital, feed, labor, and health costs; and (3) higher-index boars in the smaller population deliver greater genetic value per dose to the sow farm customer. This triple advantage is why the GTC stage shows the clearest and most direct economic benefit from PCAI adoption, but only when semen concentration is reduced, rather than simply switching catheter types while maintaining CAI-level sperm numbers.

2.2.5 Sow Farm Production Costs

One of the most prevalent modern production systems in commercial pork production is the three-site, all-in/all-out (AIAO) system, consisting of a breeding-gestation-farrowing site, a nursery site, and a grower-finishing site (Dhuyvetter, et al. 2014). The adoption of AIAO systems has contributed to improved disease management by reducing cross-contamination between pig age groups and enabling full depopulation and sanitation between production cycles. Production costs and net returns at the sow farm level are highly dependent on production efficiency, which varies due to genetics, health status, nutrition programs, facility design, and management quality (Dhuyvetter, et al. 2014).

The primary productivity metric at the sow farm level is pigs weaned per mated female per year (PWMFY), which integrates two key variables: pigs weaned per litter and litters per sow per year. These two factors together determine the total number of weaned pigs produced per sow annually, which is the core economic output of the sow farm stage. The PWMFY metric is particularly relevant to the AI technique comparison in this thesis, as CAI, PCAI and DIUI; by enabling access to higher-index semen and the genetic improvements it carries, directly influence born alive, weaned per litter, and ultimately PWMFY over time.

According to the most recent USDA Quarterly Hogs and Pigs report (December 23, 2025) (USDA, National Agricultural Statistics Service 2025), the total U.S. hog and pig inventory as of December 1, 2025 stood at 75.5 million head, up 1% from December 2024.

Of this total, 69.6 million were market hogs and 5.95 million were kept for breeding. Between September and November 2025, 35.0 million pigs were weaned on U.S. farms, with an average of 11.93 pigs weaned per litter, the highest quarterly average on record (USDA, National Agricultural Statistics Service 2025).

The March 27, 2025, Quarterly Hogs and Pigs report (reporting the March 1, 2025, inventory) showed 74.5 million total hogs and pigs, with a breeding inventory of 5.98 million head, down 1% from the prior year. During the December 2024–February 2025 period, an average of 11.65 pigs were weaned per litter (USDA NASS, 2025). Iowa accounted for the largest state inventory at 24.3–25.3 million head, and hogs under contract to operations with more than 5,000 head accounted for 52% of total U.S. inventory, unchanged from the prior year, reflecting the continuing consolidation trend documented in the broader literature (R. Knox 2025) (Kim, et al. 2024).

Table 2.11 U.S. Hog and Pig Inventory Trends 2025 (USDA NASS Quarterly Hogs and Pigs Reports)

Metric	March 1 2025	June 1 2025	September 1 2025	December 1 2025
All hogs and pigs (million head)	74.5	75.1	74.5	75.5
Breeding inventory (million head)	5.98	5.98	5.93	5.95
Market hog inventory (million head)	68.5	69.2	68.5	69.6
Pigs weaned/litter (quarter avg.)	11.65 (Dec–Feb)	11.75 (Mar–May)	11.77 (Jun–Aug est.*)	11.93 (Sep–Nov)
Sows farrowing (million, quarter)	2.89	2.91	2.88	2.93

*Source: USDA, National Agricultural Statistics Service (NASS). Quarterly Hogs and Pigs reports: March 27, June 26, September 25, and December 23, 2025. *June–August pigs per litter estimated; Sep–Nov 2025 figure (11.93) is highest quarterly average on record.*

The Production Analysis Summary for U.S. Pork Industry (2020–2024) (Metafarms, Inc. & National Pork Board 2025), representing 1.28 million females from 462 sow farms, provides the most current industry-wide benchmarking dataset available. Key findings from the 2024 report reflect five years of sustained productivity improvement:

Pigs weaned per mated female per year (PWMFY) reached 27.27 in 2024, up from 25.42 in 2020; an improvement of 7.3% over the five-year period, with a particularly strong gain of +1.2 in 2024 alone. Total born increased from 14.7 pigs per litter in 2020 to 15.6 in 2024, while pigs weaned per sow rose from 10.99 to 11.64. The farrowing rate remained in a tight 83–84% band throughout the period, indicating that improvements in total output were driven primarily by litter size gains rather than farrowing frequency (Metafarms, Inc. & National Pork Board 2025).

Pre-wean mortality, however, remains a significant challenge. The 2024 value of 17.0% was higher than the 2020 value of 16.8% and came off a five-year high of 17.5% in 2023. As litter sizes have increased, maintaining neonatal care quality has become more operationally demanding, and the industry has not yet converted the full genetic and reproductive gains into survivable weaned pigs. Sow mortality showed a positive reversal in 2024, declining to 12.2% from a five-year high of approximately 14% in 2022, the first meaningful decrease in five years, attributed to improved animal husbandry, better health programs, and veterinarian-producer collaboration (Metafarms, Inc. & National Pork Board 2025).

Table 2.12 U.S. Sow Farm Productivity Benchmarks 2020–2024

KPI	2020	2021	2022	2023	2024
PWMFY (pigs weaned/mated female/year)	25.42	25.8	26.0	25.98	27.27
Total Born / litter	14.7	15.0	15.2	15.3	15.6
Pigs Weaned / sow farrowed	10.99	11.2	11.3	11.19	11.64
Farrowing Rate (%)	83–84%	83–84%	83–84%	83–84%	83–84%
Pre-Wean Mortality (%)	16.8%	~16.5%	~16.8%	17.5%	17.0%
Sow Mortality (%)	~13%	~13.5%	~14%	~13.8%	12.2%

Source: MetaFarms, Inc. and National Pork Board (2025). Production Analysis Summary for U.S. Pork Industry: 2020–2024. Dataset: 1.28 million females from 462 sow farms.

The cost of producing a weaned pig is the primary economic output metric of the sow farm stage and the key input price for the subsequent Wean-to-Finish analysis. According to the Agri-Stats December 2025 report (Period: Sep–Nov 2025), the weighted average total cost per weaned pig in North American commercial operations was $35.20, with the top 25% of operations achieving $29.43 per head; a gap of $5.77 per weaned pig between average and top-tier performers.

The cost structure at the sow farm level is dominated by facility and labor costs. As reported by Agri-Stats (2025), facility costs account for 51% of total weaned pig cost, feed ingredients for 28%, medications and vaccines for 7%, sow replacement costs for 5%, semen for 4%, mill and delivery for 3%, and farm services for 2%. Within the facility category, labor is the single largest line item at $9.26 per weaned pig on average ($7.81 for top 25%), followed by lease and depreciation at $3.57 ($2.70 top 25%), and maintenance at $2.76 ($1.83 top 25%).

Table 2.13 Weaned Pig Cost Structure, $/Weaned Pig, Sep–Nov 2025

Cost Category	% of Total	Average ($/WP)	Top 25% ($/WP)	Avg vs. T25% Difference
TOTAL WEANED PIG COST	100%	$35.20	$29.43	$5.77
Facility (total)	51%	~$17.95	~$15.01	↓
• Labor ($/WP)	~46% of fac.	$9.26	$7.81	$1.45
• Lease & Depreciation ($/WP)	~18% of fac.	$3.57	$2.70	$0.87
• Maintenance ($/WP)	~14% of fac.	$2.76	$1.83	$0.93
• Electricity ($/WP)	~4% of fac.	$0.82	$0.66	$0.16
• Waste Management ($/WP)	~4% of fac.	$0.80	$0.24	$0.56
Feed Ingredients	28%	~$9.86	~$8.24	↓
Med & Vaccine	7%	~$2.46	~$2.06	↓
Sow Cost (replacement)	5%	~$1.76	~$1.47	↓
Semen Cost	4%	~$1.41	~$1.18	↓
Mill & Delivery	3%	~$1.06	~$0.88	↓
Farm Service	2%	~$0.70	~$0.59	↓

Source: Agri-Stats, Inc. (2025). December 2025 Summary, Period Sep–Nov 2025 [PIC Internal Report]. Category breakdowns (~) are estimated from the reported percentage distributions applied to total cost figures. Direct line-item $/WP values are from facility detail slide. Total weaned pig cost does not include market haul costs.

The semen cost category (4% of total weaned pig cost, approximately $1.41/weaned pig on average) is directly relevant to the AI technique comparison in this thesis. This represents the aggregate cost of all semen doses, delivery, boar stud operations, and genetic royalties divided by the total weaned pigs produced. Under PCAI protocols where reduced sperm concentration per dose enables production of more doses per ejaculate and access to higher-index semen. The semen cost per weaned pig could be affected in multiple directions: higher per-catheter cost partially offset by dose yield efficiency gains, while the genetic value embedded in each dose increases. The NPV model in Chapter IV quantifies this trade-off explicitly.

Feed represents 28% of total weaned pig cost but is the single most variable cost driver because it is sensitive to commodity markets. Agri-Stats (Dec 2025) data for the Sep–Nov 2025 period shows total feed cost per sow per day at $212.82/ton average ($207.38/ton top 25%), with lactation feed running $247.19/ton average and gestation feed at $195.52/ton. Average total feed consumption was 6.99 lb/sow/day (6.96 lb top 25%), with gestation at 5.35 lb/sow/day and lactation at 17.98 lb/sow/day (Agri-Stats, Inc., 2025).

The Dhuyvetter et al. (2014) facility cost benchmarks below reflect 2013–2014 construction prices and are substantially below current market rates. The Agri-Stats (2025) data provides the most current measure of realized facility cost per weaned pig ('51% of cost structure' at ~$17.95/WP average). For capital budgeting reference, the Dhuyvetter figures should be inflated by at least 40–60% to approximate 2024–2025 construction costs, consistent with Compeer Financial (Compeer Financial 2024)data on swine building cost trends.

Capital investment in farrowing facilities varies substantially with facility type and size. A central farrowing house with liquid manure facilities and slotted floors is estimated at $2,508 per sow (66 sq. ft. per sow), with internal equipment adding an additional $1,150 per sow. The gestation building is estimated at $600 per sow (20 sq. ft. per sow), with equipment at $235 per sow (Dhuyvetter, et al. 2014). Office facilities, site preparation, and miscellaneous items represent additional capital requirements. The critical economic implication of these fixed capital costs is that they are independent of production level, meaning that higher productivity per sow directly reduces the facility cost per weaned pig, reinforcing the economic value of genetics programs that maximize PWMFY.

The market price of weaned pigs is the primary revenue driver at the sow farm stage and a key input assumption for the NPV model. According to the USDA National Direct Feeder Pig Report, weaned pig prices were highly elevated throughout 2025 relative to prior years, driven by strong packer demand, lean inventories, and favorable lean hog futures prices (USDA, AMS 2025).

For early weaned pigs (10–12 lb basis), the weighted average cash price ranged from approximately $54–$83 per head during 2025, versus approximately $35/head for the same period in 2024; an increase of approximately 50–130% year-over-year (USDA, AMS 2025). Feeder pigs at the 40-pound basis ranged from $74.55 to $112.33 per head during the year, compared to approximately $49/head one year earlier.

Table 2.14 Weaned Pig and Feeder Pig Market Prices, 2025 vs. Prior Year

Category	2025 Range ($/head)	2025 Avg. ($/head, approx.)	2024 Comparable ($/head)	YoY Change
Early weaned (10–12 lb), cash	$40–$95	~$65	~$35–$45	+50–130%
Early weaned (10–12 lb), formula	$49–$90	~$60	~$35–$43	+50–100%
Feeder pigs (40 lb), cash	$74.55–$112.33	~$90	~$45–$55	+80–100%

Source: USDA Agricultural Marketing Service, Livestock, Poultry and Grain Market News Division. National Direct Feeder Pig Report (LSD_MARS_2810). Weekly reports, January–August 2025. Prices are per head, delivered, and include freight and fees. Note: prices are highly volatile and depend on seasonality, lean hog futures, feed costs, and supply-demand dynamics. These figures represent the most recent available data at time of thesis completion and are not guaranteed to remain stable through the defense and publication period.

The significant increase in weaned pig prices during 2025 reflects the tight supply-demand balance in the North American feeder pig market and the strong profitability environment for packer-level hog production. This price environment is important context for the sow farm NPV analysis: at higher weaned pig prices, the incremental revenue from producing one additional weaned pig per litter, a direct benefit of genetic improvement enabled by CAI, PCAI and DIUI is substantially larger in dollar terms than was captured in the original thesis model, which used lower historical price assumptions.

Table 2.15 Sow Farm Production and Cost Parameter

Parameter	Current Benchmark (2024–2025)
PWMFY (industry avg.)	27.27 (MetaFarms/NPB, 2025); 27.61–29.15 (Agri-Stats, 2025)
Pigs weaned / litter	12.27–12.56 avg/T25% (Agri-Stats, 2025); 11.65–11.93 (USDA NASS, 2025)
Total Born / litter	15.93–16.05 (Agri-Stats, 2025); 15.6 (MetaFarms, 2025)
Pre-Wean Mortality	15.14–17.0% (Agri-Stats 2025 / MetaFarms 2025)
Sow Mortality	12.2–14.29% (MetaFarms 2025 / Agri-Stats 2025)
Total weaned pig cost	$35.20 avg; $29.43 top 25% (Agri-Stats, 2025)
Weaned pig market price (10–12 lb)	$54–$83 cash (USDA AMS, 2025)
Farrowing rate	83–84% avg (MetaFarms, 2025)
U.S. Breeding herd	5.93–5.98 million (USDA NASS, 2025)

Sources: National Pork Board (2011); PIC (2006); USDA (2014); Koketsu & Sasaki (2009). Current benchmarks; MetaFarms, Inc. and National Pork Board (2025); Agri-Stats, Inc. (2025); USDA NASS Quarterly Hogs and Pigs (2025); USDA AMS National Direct Feeder Pig Report (2025).

The data above reveals an average weaned pigs per litter of 12.27–12.56, PWMFY has grown from approximately 27–30 range. An increase in this KPIs in the last decade reinforce rather than undermine the thesis argument: as litter sizes grow and sow productivity improves, the marginal value of genetic quality per dose, the core economic driver of PCAI and DIUI adoption, compounds across larger and more productive litters, amplifying the NPV advantage of superior AI techniques over the model's five-year horizon.

2.2.6 Wean-To-Finish Production Costs

The Wean-to-Finish (WTF) stage represents the third link in the commercial pork production chain, encompassing the period from weaning (approximately 21 days of age, ~12–14 lb) through market weight (approximately 275–295 lb). Depending on the production system, this stage may be structured as a single continuous Wean-to-Finish site or as two sequential phases: a nursery phase (wean to approximately 50–60 lb) and a grow-finish phase (50 to 275+ lb) in a three-site, all-in/all-out system (Dhuyvetter, et al. 2014).

Facilities represent the largest fixed capital investment at this stage. A nursery building with total slotted floors costs approximately \$125 per pig (3.5 sq. ft. per pig) with internal equipment adding \$13 per pig. A total confinement finishing building with a deep pit manure system is estimated at \$188 per pig (7.5 sq. ft. per pig), with equipment adding \$29 per pig (Dhuyvetter, et al. 2014). As with all capital benchmarks from this reference, these figures predate the significant construction cost inflation of 2020–2023 documented by (Compeer Financial 2024) and should be treated as directional floor-level estimates only.

Dhuyvetter et al. (2014) facility costs represent 2013–2014 prices. Based on Compeer Financial (2024) data on swine building cost inflation, current facility costs are estimated to be 40–60% higher than these benchmarks. The Agri-Stats (2025) data on facility cost per cwt provides the most current realized measure of facility cost across the production chain.

Feed is the dominant variable cost at the WTF stage, typically representing 45–55% of total grow-finish production cost. The key performance metrics that drive both feed efficiency and overall profitability are Average Daily Gain (ADG), Feed Conversion Ratio (FCR), Days to Market, and Mortality Rate. These are also the metrics where the genetic improvement enabled by PCAI and DIUI at the GTC level delivers its most tangible downstream economic value: superior genetics improve ADG and FCR, reduce days to market, and lower mortality, collectively reducing the cost per pound of pork produced while increasing revenue per head marketed.

Genetic Value at WTF Stage: This is the production stage where the genetic value of AI technique decisions is ultimately monetized in cash terms. A 0.05 improvement in

FCR across a wean-to-finish system represents a direct reduction in feed cost per head. For a 10,000-head finishing barn cycling 2.5 turns per year, even a $1.50/cwt improvement in feed efficiency translates to approximately $100,000 in annual cost savings. This downstream genetic value is the primary justification for the premium placed on higher-index semen in the thesis NPV model.

The December 2025 Agri-Stats report (Sep–Nov 2025 period) provides the most current published benchmarks for grow-finish and wean-to-finish performance. These figures are presented for both production system types, with Grow-Finish (GF) representing three-phase operations and Wean-to-Finish (WTF) representing single-site continuous systems. All data are adjusted to a 275 lb hog weight basis for comparability.

Table 2.16 Grow-Finish and Wean-to-Finish Monthly Performance Indicators

Indicator	GF Avg.	GF Top 25%	WTF Avg.	WTF Top 25%	Nursery Avg. (Dec 2025)
Final / End Weight (lb)	292.88	294.03	287.03	294.69	59.02
Age at market (days)	183	180	180	174	69 (end of nursery)
ADG (lb/day)	2.08	2.12	1.73	1.79	0.95
FCR (lb feed/lb gain)	2.84	2.80	2.64	2.43	1.54
Mortality (%)	4.90%	4.88%	10.01%	5.80%	4.41%

Source: Agri-Stats, Inc. (2025). December 2025 Summary, Period Sep–Nov 2025 [PIC Internal Report]. Grow-Finish = three-phase finishing system. Wean-to-Finish = single-site continuous system from wean to market. Nursery data from same report (50 lb pig weight basis, caloric conversion adjusted). ADG and FCR are not adjusted by weight, per Agri-Stats methodology. Note: WTF average mortality (10.01%) includes the nursery phase, accounting for the higher total mortality vs. GF-only (4.90%).

Several observations from these benchmarks are directly relevant to the thesis economic model. First, the Top 25% WTF FCR of 2.43 versus the average of 2.64 represents a 0.21-unit advantage, equivalent to approximately 10–12 lb less feed per pig marketed. At current feed ingredient costs of approximately $24–25 per cwt (Agri-Stats, Inc. 2025), this FCR advantage translates to roughly \$2.50–\$3.00 per pig in direct feed cost savings. Second, the ADG advantage of top performers (1.79 vs. 1.73 lb/day in WTF) reduces days to market by approximately 6 days for a 275-lb hog, reducing fixed facility cost per pig marketed. Third, the 4.21-percentage-point mortality gap between average and top 25% WTF operations (10.01% vs. 5.80%) represent the single largest performance differentiator in terms of pig survival to market.

The MetaFarms 2024 Production Analysis (Metafarms, Inc. & National Pork Board 2025) provides complementary industry-wide context. The 2024 average finisher feed conversion in the MetaFarms database was 2.86, with the top 10% achieving 2.62 and average finisher mortality at 4.8%. Nursery and wean-to-finish mortality rates were declining in 2024 relative to 2023, an encouraging trend that Knox (2025) attributes in part to improved health management programs and genetic selection for resilience. The convergence of the Agri-Stats and MetaFarms benchmarks, two independent datasets that provide high confidence in the parameter ranges used for the NPV model.

Production cost at the grow-finish stage is primarily driven by the cost of the incoming pig (feeder pig or weaned pig) and feed ingredients. The Agri-Stats December 2025 report provides a detailed cost breakdown for both GF and WTF systems:

Table 2.17 Grow-Finish Cost, \$/cwt

Cost Category	**Average (\$/cwt)**	**Top 25% (\$/cwt)**	**Avg vs. T25% Difference**
Total Finishing Cost, \$/cwt	\$52.31	\$47.17	\$5.14
Pig Cost @ Entry, \$/cwt	\$100.89	\$87.55	\$13.34
Feed Ingredient Cost, \$/cwt	\$21.20	\$19.85	\$1.35
Facility Cost, \$/cwt	\$5.78	\$4.93	\$0.85

Source: Agri-Stats, Inc. (2025). December 2025 Summary, Period Sep–Nov 2025 [PIC Internal Report]. Pig Cost @ Entry (\$/cwt) is not included in total finishing cost — it represents the feeder pig transfer or purchase price which is a separate input cost. All \$/cwt figures are on a 100-lb live weight basis.

Table 2.18 Wean-to-Finish Cost, $/cwt and W2F Index Summary

Cost Category	WTF Avg. ($/cwt)	WTF T25% ($/cwt)	W2F Index Avg. ($/cwt)	W2F Index T25% ($/cwt)
TOTAL W2F COST, $/cwt	$49.23	$47.41	$51.19	$47.08
Pig Cost @ Entry, $/cwt	$261.67	$212.64	N/A	N/A
Feed Ingredient, $/cwt	$24.60	$24.60	$24.98	$24.23
Facility Cost, $/cwt	$6.95	$6.81	$7.81	$6.86
Feed Mill & Delivery, $/cwt	N/A	N/A	$2.68	$2.28
Medication & Vaccine, $/cwt	N/A	N/A	$1.12	$1.14
Live Haul, $/cwt	N/A	N/A	$0.90	$0.97
Farm Service, $/cwt	N/A	N/A	$0.43	$0.38

Source: Agri-Stats, Inc. (2025). December 2025 Summary, Period Sep–Nov 2025 [PIC Internal Report]. W2F Index Summary equalizes 3-phase finishers to a theoretical wean-to-finish program for direct comparison. Pig Cost @ Entry for WTF ($261.67 avg) represents the weaned pig cost carried into the finishing stage and is not included in the W2F operational cost total. Feed is the dominant operational cost at 49–66% of total W2F cost depending on the cost structure.

A critical observation from these cost tables is that feed ingredients account for the same absolute $/cwt in both average and top 25% WTF operations ($24.60 for both, from the WTF data), indicating that feed costs are largely commodity-driven and not a major source of operational differentiation between performers. The primary differentiators between average and top 25% operations are the pig cost at entry ($261.67 vs. $212.64, a $49.03/cwt gap) and facility efficiency ($6.95 vs. $6.81/cwt). This finding has a direct implication for the thesis argument: since commodity feed costs are non-differentiating between operations, the primary pathway to cost advantage is through pig quality at entry, which is directly influenced by genetics and AI technique decisions at the GTC and sow farm levels.

Feed cost is the single most volatile variable cost in WTF production due to its sensitivity to corn and soybean meal prices, which are driven by global supply and demand, weather, energy markets, and trade policy. Langemeier (Langemeier, Prospects for Swine Feed Costs in 2025 2024) estimated the swine finishing feed cost at approximately $33.50

per cwt in late 2024, with projections for 2025 ranging from $27 to $35 per cwt depending on corn ($3.50–$4.50/bu) and soybean meal ($250–$350/ton) price scenarios. An updated mid-2025 analysis (Langemeier, Prospects for Swine Feed Costs in the Second Half of 2025 2025) placed current finishing feed costs at approximately $36 per cwt, with the feed cost index projected at 88, approximately 12% below the 2024 average; reflecting moderating grain prices (Langemeier, Prospects for Swine Feed Costs in 2025 2024).

The price sensitivity of feed costs is well-established: each $0.10/bushel increase in corn price raises finishing feed cost by $0.43/cwt, while each $10/ton increase in soybean meal price raises it by $0.37–$0.38/cwt (Langemeier, Prospects for Swine Feed Costs in 2025 2024). This sensitivity underscores why FCR is the most economically consequential performance parameter at the WTF stage: a 0.05-unit improvement in FCR at a corn price of $4.25/bu reduces feed cost by approximately $1.50–$2.00 per pig marketed, regardless of the absolute feed price level. The genetic improvement in FCR enabled by higher-index boars, disseminated through PCAI is therefore a perpetual, compounding cost advantage at this production stage.

The market hog total cost: integrating sow farm, nursery, and finishing costs, is the bottom-line measure of competitiveness for integrated operations and a key input to the thesis NPV model. The Agri-Stats December 2025 data (Period: Sep–Nov 2025) provides the most current full-chain cost and price comparison for North American operations:

Table 2.19 Market Hog Full-Chain Cost and Profitability (Agri-Stats, Inc., Dec 2025, 275 lb adjusted)

Metric	Month Avg.	Month T25%	3-Month Avg.	3-Month T25%	12-Month Avg.	12-Month T25%
Market Hog Price ($/hog)	$170.14	$173.31	$191.68	$198.30	$184.50	$186.89
Market Hog Cost ($/hog)	$141.71	$132.11	$147.10	$139.73	$148.83	$135.41
Margin ($/hog)	$28.44	$41.20	$44.58	$58.58	$35.67	$51.48

Source: Agri-Stats, Inc. (2025). December 2025 Summary, Period Sep–Nov 2025 [PIC Internal Report]. Market Hog Cost ($/hog) includes Sow Farm + Nursery + Finishing costs. Price is average realized market price per hog marketed. All figures adjusted to 275 lb live weight basis.

Table 2.20 Market Hog Full-Chain Cost Components, $/Pig (Agri-Stats, Inc., Period Sep–Nov 2025)

Cost Category	Period Avg. ($/pig)	Period T25% ($/pig)	% of Total (Avg.)	T25% vs. Avg.
TOTAL Market Hog Cost	$145.39	$132.91	100%	$12.48 ↓
Feed Ingredient (all stages)	$80.71	$77.69	55.5%	$3.02 ↓
Facilities & Labor (all stages)	$42.05	$36.49	28.9%	$5.56 ↓
Feed Mill & Delivery	$8.77	$7.29	6.0%	$1.48 ↓
Medication & Vaccine	$5.69	$5.14	3.9%	$0.55 ↓
Freight In	$2.59	$2.26	1.8%	↓
Farm Service	$1.98	$1.38	1.4%	$0.60 ↓
Parent Stock (sow genetics)	$3.60	$2.64	2.5%	$0.96 ↓

Source: Agri-Stats, Inc. (2025). December 2025 Summary, Period Sep–Nov 2025 [PIC Internal Report]. Parent Stock cost includes sow and gilt inventory value, royalties, and cull sow revenue net. Note: feed ingredient is the dominant cost at 55.5% of total, followed by facilities & labor at 28.9%.

The economic gap between top-performing and average operations is a central theme of the Agri-Stats benchmarking data and directly supports the thesis argument for investing in superior genetics and AI technique optimization. The December 2025 Agri-Stats report quantifies this gap per pig marketed across three timeframes:

Table 2.21 Top 25% vs. Average Advantage per Pig (Agri-Stats, Inc., Dec 2025)

Advantage Component	Month ($/pig)	3-Month Period ($/pig)	12-Month ($/pig)
Cost Advantage (Top 25% lower cost)	$9.60	$7.37	$13.42
Price Advantage (Top 25% higher price)	$3.16	$6.63	$2.39
TOTAL Advantage per Pig	$12.76	$14.00	$15.81

Source: Agri-Stats, Inc. (2025). December 2025 Summary, Period Sep–Nov 2025 [PIC Internal Report]. Cost advantage = lower total cost per pig. Price advantage = higher realized sale price per pig (reflecting better carcass merit, yield, and quality premiums). Total advantage is the sum of both components.

The 12-month trailing advantage of $15.81 per pig between top 25% and average operations, composed of $13.42 in cost advantage and $2.39 in price advantage is a quantitative expression of what best-in-class management, genetics, and facility efficiency deliver at the market level. Importantly, the price advantage ($2.39–$6.63/pig) reflects higher carcass merit and quality premiums obtained by top producers, a benefit that flows directly from superior genetics disseminated through effective AI programs. This aligns precisely with the thesis argument: PCAI and DIUI, by enabling wider dissemination of higher-index boar genetics, contributes to both the cost and price components of this competitive advantage, compounding across the entire production chain.

The US hog market in 2024–2025 has been characterized by favorable profitability for integrated producers. The USDA (USDA, Economic Research Service 2025) projected live equivalent hog prices of 51–52% lean to average approximately $61.14/cwt for full-year 2025, with Q3 2025 forecast at $65/cwt. Iowa State University estimated returns for a wean-to-finish operation showed profits averaging approximately $14.99 per head over the six months January–June 2025, ranging from $5.49 to $21.95/head (ISU, 2025). The Agri-Stats data confirms this profitability picture, with the 3-month average margin of $44.58/pig (average) and $58.58/pig (top 25%) for the Sep–Nov 2025 period.

Feed costs, the primary variable driver of WTF profitability, have declined substantially since their 2022–2023 highs. Total feed costs per head for WTF operations fell from approximately $108.70/head in July 2023 to $82.42/head by July 2024; a 24.2% reduction driven by the decline in corn prices from above $6.50/bu to approximately $4.20–$4.50/bu (Iowa State University Extension 2024-2025). This favorable feed cost environment has significantly improved WTF margins, creating a window in which the additional investment in higher-index genetics and advanced AI techniques is more easily justified on NPV terms.

However, Knox (2025) cautions that the industry faces ongoing profitability volatility from several structural sources: PRRS and ASF disease risks, export market instability (particularly from tariff uncertainties with China and Mexico), environmental and welfare regulatory costs, and labor availability constraints. The Agri-Stats data confirms that PRRS impacts remained significant in 2025, with the USDA ERS (2025) reporting that PRRSV Lineage 1C.2 severely affected WTF sites with high mortality rates through mid-2025. This disease risk context reinforces the long-term value proposition of genetics programs that integrate disease resistance traits, including CRISPR/Cas9-edited PRRS-resistant pigs currently approaching commercial readiness (R. Knox 2025) (Brian T Burger 2024).

Table 2.22 Grow-to-Finish Parameter 2024–2025

Parameter	Current Benchmark (2024–2025)
Nursery facility cost	Agri-Stats 2025: $6.01/hd facility (≈$6–$7/hd current realized cost)
Finishing facility cost	Agri-Stats 2025: $5.78–$6.95/cwt facility realized cost
Grow-Finish ADG (lb/day)	2.08 avg / 2.12 T25% (Agri-Stats, 2025)
Grow-Finish FCR	2.84 avg / 2.80 T25% (Agri-Stats, 2025); 2.86 avg (MetaFarms, 2025)
WTF FCR	2.64 avg / 2.43 T25% (Agri-Stats, 2025)
Days to market	183 avg / 180 T25% GF; 180 avg / 174 T25% WTF (Agri-Stats, 2025)
GF Mortality	4.90% avg / 4.88% T25% (Agri-Stats, 2025); 4.8% (MetaFarms, 2025)
WTF Total Mortality	10.01% avg / 5.80% T25% (Agri-Stats, 2025)
Total Market Hog Cost ($/pig)	$145.39 avg / $132.91 T25% (Agri-Stats, 2025, period)
Feed ingredient cost $/cwt	$21.20/cwt GF; $24.60/cwt WTF (Agri-Stats, 2025)
Feed cost/cwt (finishing)	$33.50–$36/cwt (Langemeier, 2024–2025)
Market hog price ($/hog)	$147.10–$191.68 avg; $139.73–$198.30 T25% (Agri-Stats, 2025)

Sources: Agri-Stats, Inc. (2025); MetaFarms/NPB (2025); Langemeier, Purdue Center for Commercial Agriculture (2024–2025); Iowa State University Estimated Returns (2024–2025).

2.2.7 Slaughterhouse Production Cost

The slaughterhouse, also referred to as the packing plant or processing facility, is the final link in the commercial pork production chain and the stage where all upstream genetic, production, and management decisions are converted into carcass value and ultimately into market revenue. This stage receives live market hogs from grow-finish or wean-to-finish operations, converts them into dressed carcasses and primal cuts, and sells the resulting pork products to wholesale, retail, and export buyers. Revenue at this stage is determined by hot carcass weight (HCW), lean percentage, and the base carcass price plus applicable quality premiums or discounts paid by the packer under the applicable grid pricing program.

From the producer's economic perspective, the stage of slaughter is where the genetic value embedded at the GTC level and disseminated through CAI, PCAI or DIUI. It is finally captured in a dollar-per-head format. Superior genetics improve both the yield (more lean pounds per carcass) and the quality (higher lean percentage, better loin depth, lower backfat) of pork carcasses, resulting in more favorable placement on packer pricing grids and higher revenue per hog marketed. This downstream carcass merit value is the final economic component of the NPV model and is the one most directly attributable to genetic selection decisions made at the beginning of the production chain.

The Genetic Value at Slaughter: The entire genetic value argument of this thesis converges at the slaughterhouse: CAI, PCAI and DIUI enable wider dissemination of higher-index semen, which improves ADG and FCR at WTF (reducing cost), and improves HCW, lean percentage, and loin depth at slaughter (increasing revenue). Both effects simultaneously improve NPV. The slaughter stage is where the 'revenue side' of the genetic value equation is captured.

The U.S. pork packing industry is highly concentrated. According to the USDA NASS Livestock Slaughter Annual Summary (2025), a total of 129.05 million hogs were federally inspected and slaughtered in the United States during 2024, a figure representing essentially all commercial pork production, as over 99% of U.S. hog slaughter occurs in federally inspected (FI) plants (USDA, National Agricultural Statistics Service 2025). The number of FI hog slaughter plants increased from 659 in 2022 to 763 in 2024, driven primarily by USDA grants to expand small and medium-sized processing facilities. However, this plant count increase did not materially expand industry-wide slaughter capacity: the 44 new small plants added in 2024 combined represented less capacity than was lost when Tyson Foods closed its Perry, Iowa plant in June 2024 (National Hog Farmer 2025).

In practice, large plants dominate throughput. The largest plants; those responsible for nearly two-thirds of total U.S. pork slaughter, average approximately 21,450 head per day over approximately 256 slaughter days per year (National Hog Farmer 2025). Industry concentration in pork packing mirrors the consolidation trend documented across the production chain: a small number of companies, including Smithfield Foods, JBS USA, Tyson Foods, Seaboard Foods, and Triumph Foods; account for the majority of commercial pork processing capacity. Pork packer capacity utilization ranged from approximately 76% to 96% during 2025, with the highest utilization in Q4 2025 at approximately 95.7% (Sterling Marketing 2025).

U.S. commercial pork production totaled 27.572 billion pounds in 2025, slightly below the 27.789 billion pounds produced in 2024, reflecting modestly lower slaughter numbers partially offset by heavier average carcass weights (USDA, Economic Research Service 2025). Approximately 27% of commercial pork production is exported, making pork exports the second-largest destination for U.S. pork after domestic consumption. Mexico remains the largest foreign customer, with monthly export volumes exceeding 250 million pounds in recent months, while Japan, South Korea, and Canada are additional major markets (USDA, Economic Research Service 2025).

Table 2.23 U.S. Pork Slaughter Industry Key Metrics

Metric	Value	Source
Total FI hog slaughter (2024)	129.05 million head	USDA NASS, 2025
U.S. commercial pork production (2025)	27.572 billion lb	USDA ERS, 2025
U.S. commercial pork production (2024)	27.789 billion lb	USDA ERS, 2025
Total FI slaughter plants (2024)	763 plants	USDA NASS, 2025
Largest plants throughput (avg)	~21,450 head/day (2/3 of total)	National Hog Farmer, 2025
Packer capacity utilization (2025 range)	~76–96% (peak Q4: 95.7%)	Sterling Marketing, 2025
Pork exports (% of production)	~27% of commercial production	USDA ERS, 2025
Hog prices (live equiv., 2025 avg.)	$68.80/cwt (highest since 2022)	Ron Plain, U. Missouri, 2026
Pork cutout value (peak 2025)	~$120/cwt (late June 2025)	National Hog Farmer, 2025

The price a packer pays for a market hog and hence the revenue that flows back to the grow-finish operator and, upstream, to the sow farm is determined by a lean value buying program. The three primary determinants of carcass value under industry-standard packer grid programs are: (1) hot carcass weight (HCW), (2) fat depth at the 10th rib (backfat), and (3) loin muscle depth at the 10th rib. These measurements, obtained using optical probes (Fat-O-Meater or equivalent) or ultrasound systems on the slaughter line, are used to calculate predicted lean percentage and place the carcass on the packer's pricing grid (USDA, AMS 2025).

Commercially bred market hogs have a dressing percentage in the range of 70–75% (average approximately 72%), meaning a 275-lb live hog yields approximately 193–206 lb of hot carcass weight (University of Maine Coopertive Extension 2024). After cooling (cooler shrink of 1–3%), the cold carcass weight is slightly lower. The typical commercial carcass of 55–56% lean at 215 lb constitutes the USDA pork carcass cutout standard, which is the reference carcass used to calculate the daily Pork Carcass Cutout (PCC) value from which base prices derive (USDA, AMS 2025).

Standardized Fat-Free Lean (SFFL) is the key carcass composition metric used in packer pricing programs, estimated using validated industry equations. The most widely applied relationship at the 10th rib is: Lb. SFFL = 15.31 + 0.51 × HCW − 31.277 × backfat (in.) + 3.813 × loin depth (in.) (NPPC and AMSA 2000). This equation makes clear that both backfat reduction and loin depth improvement directly increase predicted SFFL both traits that are strongly influenced by terminal sire genetics. Superior terminal sire genetics, disseminated through effective AI programs at the GTC level, thus generate measurable increases in SFFL per carcass, translating directly into higher revenue per hog marketed under lean value grid programs.

Table 2.24 Commercial Pork Carcass Key Metrics: Industry Benchmarks

Metric	Industry Range	Commercial Average	Source
Live market weight (lb)	190–300	275–295	Agri-Stats, 2025
Dressing percentage (%)	68–77%	~72% (skin-on)	SDSU; U. Maine Ext., 2024
Hot Carcass Weight (lb) at 275 lb live	187–212	~198–200	Industry benchmark
Lean percentage (%)	50–60%	55–56%	USDA AMS; NPPC, 2000
Cooler shrink (%)	1–5%	~1–3% (large plants)	Swineweb.com, 2025
10th rib backfat (in) — commercial avg.	0.7–1.0 in.	~0.75–0.85 in.	Pork Information Gateway
10th rib loin depth (in)	2.0–3.0 in.	~2.2–2.5 in.	Pork Information Gateway
Primal cut value: Ham	18% of liveweight	~49.5 lb at 275 lb	NPB; U. Maine Ext., 2024
Primal cut value: Loin	16% of liveweight	~44 lb at 275 lb	NPB; U. Maine Ext., 2024
Primal cut value: Side (Belly + Ribs)	10% of liveweight	~27.5 lb at 275 lb	NPB; U. Maine Ext., 2024

Most U.S. market hogs are sold on a lean value (carcass merit) basis rather than on a live-weight price, reflecting the industry-wide shift from live to carcass pricing that accelerated in the 1990s. Under lean value buying programs, packers establish a base carcass price (per cwt of carcass weight) and then apply a matrix of premiums and discounts based on measured carcass leanness and weight. The base carcass price corresponds to a target carcass weight range and lean percentage range (typically 50–60% lean for premium eligibility), and carcasses outside these windows receive progressively larger discounts (Pork Information Gateway 2015).

The major determinants of the premiums or discounts applied to the packer's base carcass price are hot carcass weight, backfat depth at the 10th rib, and loin muscle depth. Most commercial packers use a lean meat ratio formula to determine premium eligibility, with the target lean percentage for maximum premium typically in the 54–58% lean range. Carcasses above the target lean threshold receive premiums of $1–3 per cwt, while those falling short of the minimum lean threshold or outside the acceptable weight window receive discounts, which can range from modest (1–2% for slightly overweight carcasses) to significant (5–10%+ for carcasses well outside the preferred weight or leanness range) (Pork Information Gateway 2015)

This lean value payment structure creates a direct economic linkage between GTC-level genetics decisions and slaughter-level revenue. Higher-index terminal sire genetics consistently produce offspring with superior loin eye area, lower backfat, and therefore higher lean percentage per carcass, placing a greater proportion of pigs in the premium zone of the packer's grid. The economic value of this improvement, expressed as additional revenue per hog marketed, is a core component of the downstream NPV calculation in Chapter IV of this thesis.

The carcass base price: the negotiated price per cwt of carcass weight before quality adjustments, is published daily by USDA AMS in the National Daily Hog and Pork Summary (LM_HG214/LM_PK602). The USDA National Daily Base Lean Hog Carcass values represent industry-weighted averages of negotiated and formula transactions. During December 2025, the lean carcass base price averaged approximately $80–81 per cwt, with the W. Cornbelt Lean Carcass Value averaging $70.64/cwt during the week of December 13, 2025, (Sterling Marketing 2025). For the full year 2025, hog prices averaged $68.80/cwt live weight equivalent, the highest since 2022; while the pork cutout value peaked at approximately $120/cwt in late June 2025 (Plain 2026).

Table 2.25 Market Hog Price, Full-Chain Cost, and Margin at Market

Metric	Month Avg.	Month T25%	3-Mo. Avg.	3-Mo. T25%	12-Mo. Avg.	12-Mo. T25%
Market Hog Price ($/hog, 275 lb)	$170.14	$173.31	$191.68	$198.30	$184.50	$186.89
Full-Chain Cost ($/hog)	$141.71	$132.11	$147.10	$139.73	$148.83	$135.41
Producer Margin ($/hog)	$28.44	$41.20	$44.58	$58.58	$35.67	$51.48
Packer Gross Margin ($/hog)*	~$18–22	N/A	~$32.51 (Jan–Aug 2025 avg.)	N/A	~$32.65 (long-run avg. since 2014)	N/A

*Sources: Agri-Stats, Inc. (2025). December 2025 Summary, Period Sep–Nov 2025 [PIC Internal Report]. *Packer gross margin ($/hog) is calculated as carcass cutout value + by-product drop value less live hog purchase cost. Sterling Marketing (2025); National Hog Farmer (September 2025 — Bellies and Bacon shed light on pork processing margins). All figures adjusted to 275 lb live weight basis. Packer gross margin long-run average: $32.65/head ($0.1536/lb) since 2014.*

Pork packer margins; defined as cutout value plus by-product drop less live hog cost, averaged $32.51 per head through the first eight months of 2025, approximately $1/head below the same period in 2024 but $9/head above the equivalent period in 2023 (National Hog Farmer 2025). The long-run average packer slaughter gross margin since 2014 has been remarkably stable at approximately $32.65/head ($0.1536/lb). Pork packer capacity utilization in Q4 2025 was estimated at 95.7%, versus 90.1% in the same period of 2024, reflecting strong seasonal demand (Sterling Marketing 2025).

The 2025 profitability environment across the pork value chain has been the most favorable since 2022. Farrow-to-finish producers averaged $27.17 per head marketed in profit during 2025; compared with $4.70/head in 2024 and a loss of $24.10/head in 2023 (Plain 2026). These figures represent the culmination of all upstream economic decisions; genetics, AI technique, sow farm management, WTF efficiency, nutrition converted into a single bottom-line margin per market hog.

In the context of this thesis, the profitability differential between average and top 25% operations of $15.81/pig annually on a 12-month trailing basis (Agri-Stats, Inc. 2025) captures the combined economic effect of superior genetics, better management, lower costs, and higher carcass quality. Of this $15.81 advantage, approximately $2.39/pig is attributable to a price advantage, meaning top 25% producers receive higher prices per hog marketed, reflecting higher carcass merit (lean percentage, loin depth) that earns premium placement on packer grids. This $2.39/pig price advantage is directly attributable in part to superior genetics at the terminal sire level and represents the slaughter-stage component of the genetic value argument underpinning CAI, PCAI and DIUI adoption.

In addition to carcass value, pork packers receive revenue from the by-product 'drop', the collective value of non-carcass components including offal (liver, heart, kidneys, lungs), fat (lard, rendered fats), blood, hides, and other materials. The by-product drop value for pork is tracked by USDA AMS (By-Product Drop Value Report, NW_LS446) and is included in packer gross margin calculations. While by-product drop values fluctuate with commodity markets, they typically add $5–$15 per head to total packer revenue, partially insulating packer profitability from declines in carcass cutout values. For the purpose of this thesis' NPV model, by-product drop value is not directly assignable to the producer level and is therefore captured in the packer margin rather than in producer revenue.

The transport of market hogs from grow-finish sites to packing plants represents a cost and welfare consideration at the junction between the WTF and slaughter stages. The December 2025 Agri-Stats report (Sep–Nov 2025) documents average live haul loads at approximately 48,000–49,500 pounds per load and approximately 166–169 head per load. The DOA (Dead on Arrival) and DIP (Distressed, Injured, or Pigs Unable to Rise) rate averaged approximately 0.35–0.44% during the period a measure of both animal welfare quality and transport management efficiency (Agri-Stats, Inc. 2025).

Transit losses (DOA and DIP) reduce realized revenue per pig placed, making transport management an economically important variable. Each percentage point increase in DOA/DIP rate on a 169-head load represents approximately 1.69 pigs lost per load, or — at a market hog value of $170–$190/head, approximately $287–$321 in lost revenue per load. This underscores why biosecurity, animal handling, and transport management are integrated into the overall production cost analysis. The live haul cost line item in the Agri-Stats W2F Index ($0.90/cwt average, $0.97/cwt top 25%) captures freight and haul costs as a direct production expense (Agri-Stats, Inc. 2025).

The slaughter stage is where the thesis' central economic argument that PCAI and DIUI deliver superior economic outcomes by enabling wider dissemination of higher-index genetics is ultimately validated in revenue terms. The connection between AI technique decisions at the GTC and dollar outcomes at the packing plant flows through a cascade of biological and economic linkages that can be explicitly quantified:

Table 2.26 Genetic Value Cascade: From GTC AI Technique to Slaughter Revenue

Stage	Genetic Improvement Mechanism	Slaughter-Level Effect	Economic Capture
GTC	Higher-index boars selected; more doses per ejaculate under PCAI	More hogs with superior genetics marketed per boar	Lower per-dose cost; more index points per dose
Sow Farm	Superior boar genetics → improved litter size, BA, pre-wean survival	More weaned pigs per sow per year	Lower cost per weaned pig
WTF	Superior terminal sire genetics → improved ADG, FCR	Faster days to market; lower feed per pound gained	Lower cost per cwt marketed
Slaughter	Superior terminal genetics → higher HCW, lean%, loin depth	More lb of lean per carcass; better grid placement	Higher price per cwt; more cwt per hog marketed
Combined	All upstream decisions converge in $/pig margin	Top 25% earn $15.81/pig more than average	$13.42 cost advantage + $2.39 price advantage (Agri-Stats, 2025)

Sources: Agri-Stats, Inc. (2025); National Pork Producers Council / Pork Information Gateway (2015); Pork Composition and Quality Assessment Procedures, NPPC/AMSA (2000); Knox (2025); Kim et al. (2024). The economic values in the bottom row are from Agri-Stats Dec 2025 (12-month trailing, Top 25% vs. average).

Kim et al. (2024) confirm this production chain linkage quantitatively: the EU produces 40% more pork per pig and the US produces 38% more pork per pig compared to China, a differential partially attributable to superior genetics disseminated through higher AI adoption rates and more concentrated terminal sire programs. Knox (2025) adds the forward-looking dimension: as litter sizes increase to 18–20 pigs born (EU prolific lines) and market weights and carcass leanness continue to improve with genetic progress, the incremental economic value of each index point in terminal sire genetics and therefore the NPV advantage of PCAI over CAI compounds over time rather than remaining static.

Table 2.27 Slaughterhouse Parameter Comparison: 2014 vs. 2024–2025

Parameter	Original Thesis Baseline	Current Benchmark (2024–2025)
Live hog price	~$50–$65/cwt (2013–2014 context)	$68.80/cwt avg. 2025 (highest since 2022; Ron Plain, 2026)
Carcass base price	~$70–$85/cwt HCW (estimated)	~$80–81/cwt HCW (USDA AMS, Dec 2025); $78.67/cwt forecast 2025 (USDA ERS)
Dressing percentage	~72% (established industry norm)	70–75%, avg. ~72% (University of Maine Ext., 2024)
Hot carcass weight (at 275 lb live)	~198 lb (72% dressing)	~198–200 lb; commercial avg. 213 lb (USDA AMS standard carcass)
Lean percentage (commercial)	~53–56% (estimated)	55–56% (USDA AMS Carcass Cutout standard)
Packer lean premium eligibility	Not specified	Lean value grid: premiums at 54–58%+ lean; discounts below 50% (Pork Info. Gateway, 2015)
Pork packer margin ($/hog)	Not specified	$32.51/head avg. Jan–Aug 2025; long-run avg. $32.65/head since 2014 (NHF, 2025)
Farrow-to-finish margin ($/hog)	Not specified	$27.17/head avg. 2025; $4.70 in 2024; -$24.10 in 2023 (Ron Plain, 2026)
Total US pork production	~22–25 billion lb (2013–2014)	27.572 billion lb (2025); 27.789 billion lb (2024) (USDA ERS, 2025)
US hog slaughter (annual)	~116–120 million head (estimated)	129.05 million head federally inspected (2024) (USDA NASS, 2025)

Sources: USDA ERS Livestock, Dairy and Poultry Outlook (2025); USDA NASS Livestock Slaughter Annual Summary (2025); USDA AMS National Daily Hog and Pork Summary (2025); Ron Plain, University of Missouri, National Hog Farmer (January 2026); National Hog Farmer (September 2025); Sterling Marketing Pork Profit Tracker (2025); Pork Information Gateway (2015); Agri-Stats, Inc. (2025).

CHAPTER III: ANALYSIS

Given the multi-stage structure of the pork industry, the most meaningful measure of the economic value added by different AI techniques is Net Present Value (NPV), analyzed through Capital Budgeting methodology. This study uses the United States commercial pork market as the basis for the economic model. The representative operation is a 5,000-sow commercial sow farm, which falls within the mid-to-large scale tier of US commercial production and is representative of the operations that are most actively evaluating PCAI adoption decisions.

The economic analysis proceeds in parallel across the four production stages: (1) Genetic Transfer Center (GTC), (2) Sow Farm, (3) Wean-to-Finish (WTF) Farm, and (4) Slaughterhouse. At the conclusion, NPV results across AI techniques are compared both as an operation-level aggregate and by individual stage. The objective is to identify the conditions under which each AI technique creates (or destroys) economic value, and to decompose that value across the four production stages so that the principal sources of benefit can be identified.

3.1 NPV Methodology and Analytical Framework

The NPV equation applied throughout this analysis is:

$$\mathbf{NPV = C_0 + \Sigma \left[C_t / (1 + r)^t \right]}$$

Where C_0 represents the initial investment outlay at Year 0, C_t represents the net cash flow in period t, r is the scenario-specific discount rate, and T is the five-year analysis horizon. A positive NPV implies that the rate of return on the investment exceeds the opportunity cost of capital, i.e., it exceeds the return available from alternative investments of equivalent risk (Brealey 2011). Supplementary metrics reported alongside NPV include the Internal Rate of

Return (the discount rate at which NPV equals zero), the Profitability Index (NPV divided by initial investment), and the incremental NPV of each scenario relative to the CAI baseline.

3.1.1 Risk-Differentiated Discount Rate Framework

A critical methodological element of this thesis, emphasized by the thesis committee during review, is that NPV analysis does not by itself account for risk. Risk must be captured through the discount rate. The principle, as articulated by Dr. Glynn Tonsor, is that a producer should only absorb the higher risk of a new process if that process also offers a commensurately higher return. Applied to AI technique selection, this translates into a discount rate structure that distinguishes established technology from new processes and from highest-uncertainty alternatives.

Table 3.1 Risk-Differentiated Discount Rate Framework

Investment Context	Discount Rate	Risk Profile	Interpretation
Risk-free (CD equivalent)	**4%**	No production or market risk	Baseline opportunity cost of capital
Sc. A — CAI (established)	**7%**	Well-understood, proven protocols	Scenario A baseline hurdle rate
Sc. B — PCAI (new process, same index)	**8%**	Protocol novelty + learning curve	Must exceed CAI to justify
Sc. C — PCAI (new process, higher index)	**8%**	Same protocol risk, paired with genetic upgrade	Full benefit scenario
Sc. D — DIUI (highest uncertainty)	**10%**	Specialized equipment, limited industry experience	Must clear a steeper hurdle

This framework operationalizes the distinction between Scenario B and Scenario C, which is central to the thesis argument. Both scenarios use identical PCAI protocols and therefore receive the same 8% discount rate. They differ only in whether the GTC-level boar selection upgrade is paired with the protocol change. Without the rate differentiation between CAI at 7% and PCAI at 8%, the Scenario B versus Scenario C distinction would lose its economic precision; with rate differentiation, it becomes the defining decision test of the analysis.

The analysis uses a five-year horizon (T = 5), consistent with the typical capital planning cycle for swine facility investments, semen processing equipment, and GTC boar inventory turnover (Yuzo Koketsu 2008), report average boar productive life of 2.5 years; thus a 5-year horizon covers approximately two complete boar population cycles). The model assumes that production parameters reach steady state within 6 months of protocol conversion, reflecting the training and standardization period documented in commercial PCAI adoptions (Garcia-Vazquez F.A. 2019).

3.2 US Commercial Pork Industry Baseline

The United States is the world's second-largest pork producer and third-largest pork exporter. The commercial breeding herd stood at approximately 5.93 million head as of December 2025 USDA NASS Quarterly Hogs and Pigs report, distributed across approximately 63,400 operations nationwide. The industry is highly consolidated: the top 25 US pork producers collectively own approximately 65% of the commercial sow inventory, and the top 10 producers account for over 50%.

The US market is selected as the basis for this analysis for several reasons. First, it is the primary commercial market for PIC's North American operations and the market context most directly relevant to the thesis' intellectual contribution. Second, US commercial PCAI adoption is at approximately 40% of sows, leaving approximately 60% of the commercial herd as the addressable market for the AI technique conversion decision this thesis analyzes (R. Knox 2025); comparative: Brazil >80%, Europe >90% for PCAI adoption. Third, the US packer grid structure; with explicit lean percentage premiums and carcass merit differentials, provides a well-defined economic mechanism through which genetic improvement captured at the GTC level flows downstream to the producer as measurable per-hog revenue. Fourth, the 2025 U.S. hog market produced the highest profitability since 2022, with farrow-to-finish margins averaging $27.17 per head per Iowa State University Estimated Returns and live hog prices averaging $68.80 per cwt per Plain (2026), establishing a supportive context for evaluating long-horizon investment decisions.

Table 3.2 US Pork Industry Baseline Parameters (Model Starting Point)

Parameter	Baseline Value	Source
U.S. commercial breeding sow inventory	5.93 million head	USDA NASS, December 2025
Number of U.S. commercial hog operations	Approximately 63,400	USDA NASS, 2025
Federally inspected slaughter (annual)	129.05 million head	USDA NASS Livestock Slaughter, 2025
U.S. commercial pork production (2025)	27.57 billion pounds	USDA ERS, 2025
PCAI adoption (% of U.S. commercial sows)	Approximately 40%	Knox, 2025
Representative operation scale	5,000-sow commercial	Mid-tier commercial (model focus)
Model analysis horizon	5 years	Standard capital budgeting horizon
2025 U.S. farrow-to-finish margin	$27.17 per head	ISU Estimated Returns, 2025
2025 U.S. live hog price (annual avg.)	$68.80 per cwt	Plain (2026), University of Missouri

3.3 NPV Model Scenarios

The analysis compares four AI technique scenarios across all four production stages. Each scenario represents a distinct combination of AI technique, sperm dose concentration, boar:sow ratio, and genetic index context. The scenarios are designed to isolate the economic effect of each variable; particularly the distinction between adopting PCAI as a protocol change alone (Scenario B) versus adopting PCAI paired with a GTC-level boar selection upgrade (Scenario C).

Table 3.3 NPV Model Scenario Structure

Scenario	AI Technique	Dose Standard	Boar:Sow Ratio	Genetic Index Context	Discount Rate
A	CAI (Baseline)	3.0×10^9 / 80–100 mL	1:150	Standard commercial boar index	**7%**
B	PCAI	1.5×10^9 / 45–50 mL	1:450	Same index as Sc. A	**8%**
C	PCAI	1.5×10^9 / 45–50 mL	1:450	Higher-index boars (+20 pts)	**8%**
D	DIUI	0.05×10^9 / 5–10 mL	1:3,000	Elite boars (+40 pts)	**10%**

Scenarios are designed as a progressive comparison. Scenario A is the economic baseline. The critical intellectual distinction is between Scenario B and Scenario C: both use identical PCAI protocols, but only Scenario C pairs PCAI adoption with a genetic selection upgrade at the GTC (enabled by the reduced boar count under the 1:450 ratio). Scenario D represents the frontier case with DIUI and elite boars at 1:3,000 ratio. Index differentials of +40 and +50 points reflect realistic selection intensity achievable in commercial GTC operations.

The core economic argument of this thesis is that Scenario B will show negative incremental NPV versus Scenario A, because PCAI-only captures modest labor and dose-yield savings that do not overcome the catheter cost premium plus the 8% risk-adjusted discount rate. Scenario C will show positive incremental NPV versus Scenario A, because the genetic improvement from higher-index boars compensates for the risk premium and then some. This distinction operationalizes the field observation that producers adopting PCAI without simultaneous genetic upgrade capture only a fraction of the available economic value.

3.4 GTC Stage Analysis

3.4.1 Boar Inventory Sizing

The GTC analysis begins with sizing the boar population required to supply semen to 5,000 breeding females under each scenario. The dose demand is derived from the sow farm requirement: at 2.25 litters per sow per year and 2.0 inseminations per pregnancy, plus a wastage allowance, a 5,000-sow operation requires approximately 29,000 doses per year.

The boar population required to meet this demand is determined by the boar-to-sow ratio, which in turn depends on the per-ejaculate dose yield enabled by the sperm concentration standard.

Table 3.4 GTC Boar Inventory by AI Technique Scenario (5,000-Sow Operation)

Parameter	Sc. A CAI	Sc. B-C PCAI	Sc. D DIUI	Source / Notes
Boar:Sow ratio	1:150	1:450	1:3,000	Waberski et al. (2019); Knox (2025)
Boars required (5,000 sows)	33	11	2	sows / boar ratio
Sperm cells per dose	3.0×10^9	1.5×10^9	0.05×10^9	Waberski et al. (2019)
Annual dose demand	29,000	29,000	29,000	5K sows × 5.8 doses/sow/year
Annual boar replacement rate	42%	42%	38%	Koketsu & Sasaki (2009)
Optimal collection interval	3–4 days	3–4 days	Case-specific	Rutten, Morrison & Reicks (2000)

The dramatic reduction in boar count under PCAI (33 to 11 head) is the structural feature that enables the genetic selection upgrade in Scenario C. With only 11 boars needed to service 5,000 sows, the producer can be substantially more selective in boar acquisition. Under DIUI (Sc. D), just 2 boars would theoretically serve the full 5,000-sow operation, creating an extreme genetic bottleneck that enables elite-tier selection but introduces concentration risk..

3.4.2 Boar:Sow Ratio Derivation Across AI Techniques

The boar:sow ratios applied in the GTC sub-model; 1:150 for CAI, 1:450 for PCAI, and 1:3,000 for DIUI are taken from the published commercial literature (Waberski, et al. 2019) (R. Knox 2025). These ratios are not theoretical maxima, but operational values calibrated to current industry practice. To demonstrate the biological logic underlying these ratios and to establish their internal consistency with peer-reviewed boar productivity benchmarks, this section derives the theoretical boar:sow ratio from first principles for each technique and compares it against the operational value used in the model.

The derivation begins with the boar productivity benchmarks reported by Rutten, Morrison, and Reicks (2000), which remain the most cited U.S. peer-reviewed reference for commercial GTC operations. Their analysis of 1,646 boars across seven United States studs reported an average of 31.4 usable doses per boar space per week at a collection frequency of 1.1 collections per week, with the standard CAI dose specification of 3.0×10^9 usable sperm cells per dose. From these values, the biological output per boar, measured as total useful sperm cells per boar space per week, is calculated as 31.4 multiplied by 3.0×10^9, equal to 94.2×10^9 cells per boar per week. This biological output is invariant to dose specification: the ejaculate yield from a given boar does not depend on how the resulting semen is subsequently divided into doses.

Annual useful sperm production per boar space, applying a 88% useful boar fraction (a standard adjustment that accounts for boars in training, replacement rotation, recovery from health events, and routine non-productive periods within a stud inventory), is approximately 4.31×10^{12} cells. The annual dose output for any given AI technique is calculated as the annual useful sperm production divided by the cells per dose specified for that technique. The theoretical boar:sow ratio is the maximum number of sows a single boar can supply at full biological utilization; and is then calculated as the annual doses per boar divided by the doses per sow per year. The model uses 5.8 doses per sow per year, derived as 2.3 inseminations per estrous cycle multiplied by 2.45 cycles per sow per year, including service wastage.

Applying these calculations across the three model AI techniques and several intermediate concentration scenarios yields the results presented in Table 3.4.2.

Table 3.5 Theoretical vs. Operational Boar:Sow Ratios by AI Technique

Technique	Cells/dose ($\times 10^9$)	Doses/wk per boar	Annual doses/boar	Theoretical ratio	Operational ratio (lit.)	Utilization
CAI	3.0	31.4	1,437	**1:248**	**1:150**	60%
PCAI	1.5	62.8	2,874	**1:495**	**1:450**	91%
DIUI	0.05	1,884	86,212	**1:14,864**	**1:3,000**	20%

Note. *Doses/week derived from Rutten et al. (2000) baseline of 31.4 usable doses/boar/wk at 3.0 × 10⁹ cells/dose, scaled inversely with cells/dose. Annual doses include 88% useful boar fraction. Theoretical ratio = annual doses/boar ÷ 5.8 doses/sow/yr. Operational ratios from Waberski et al. (2019) and Knox (2025). Bolded rows correspond to scenarios A, C, and D in the NPV model.*

Three observations follow from this derivation. First, the operational ratios consistently sit below the theoretical biological ceiling, with the gap representing operational buffer. The function of this buffer is to absorb sources of variability that would otherwise produce intermittent dose shortages: collection-day variability in ejaculate yield, dose rejection during routine quality control through motility and morphology screening, shipping and storage losses, demand spikes from synchronized estrous events on customer farms, and biosecurity reserves held to protect against disease entry into the stud.

Second, the utilization rate; the operational ratio expressed as a percentage of the theoretical maximum, varies markedly across techniques. CAI operates at approximately 60% utilization, leaving substantial reserve capacity. PCAI at the 1.5×10^9 cell standard operates at approximately 91% utilization, the most aggressive deployment of the three. This high utilization reflects more than a decade of commercial validation since Dallanora et al. (2009) confirmed equivalent fertility to CAI at this concentration; the industry has built confidence in the protocol and reduced the operational buffer accordingly. By contrast, DIUI at the 0.05×10^9 cell standard operates at only approximately 20% utilization, with theoretical capacity above 1:14,000 sows per boar that the industry has not deployed in commercial settings.

Third, the conservative DIUI deployment is not a function of biological constraint but of operational and biosecurity considerations. At a 1:14,000 ratio, a single boar would be the genetic source for nearly three commercial 5,000-sow operations, creating extreme concentration risk if that boar were lost to disease, genetic defect or fertility failure. DIUI's single-insemination protocol provides less margin for service errors than the two-insemination CAI and PCAI protocols, so a stud loss event is harder to compensate for. Knox (2025) notes that single-sire identification, the ability to trace specific doses back to specific boars, becomes operationally necessary at high boar:sow ratios for both fertility ranking and disease traceability, infrastructure that is not yet uniformly deployed in U.S. commercial GTCs. The model's use of the 1:3,000 operational ratio for DIUI therefore captures current commercial reality rather than biological potential and represents a conservative case for the DIUI scenario.

This derivation is provided as supplementary methodological transparency. The boar:sow ratios applied throughout the NPV model are the operational values from the literature. The Boar Productivity tab in the supplemental Excel model presents the full derivation alongside the hardcoded inputs and is structured to allow users to test alternative concentration specifications.

3.4.3 GTC Cost Structure

All GTC cost parameters were confirmed against current 2025 U.S. commercial GTC operations. The boar depreciation rate of $1,200 per year for CAI and PCAI reflects current industry practice with higher-value purebred boars; the higher rates of $1,600 (Sc. C) and $2,000 (Sc. D) reflect the additional acquisition cost of higher-index and elite boars. Semen processing cost per dose ranges from $1.00 (DIUI, with smaller volume per dose offsetting higher quality control intensity) to $2.50 (CAI), substantially higher than the 2006 PIC manual figure of approximately $2.00 to $2.25 per dose. Semen dose sale prices are set at $7.00 (CAI and Sc. C), $6.30 (Sc. B, reflecting partial cost recovery without full genetic premium), and $5.00 (DIUI, smaller-volume specialized doses).

Table 3.6 GTC Production Cost Assumptions by Input Category

Cost Category	Sc. A CAI	Sc. B PCAI same	Sc. C PCAI higher	Sc. D DIUI
Annual boar depreciation	$1,200/yr	$1,200/yr	$1,600/yr	$2,000/yr
Boar maintenance cost	$3,200/yr	$3,200/yr	$3,200/yr	$3,200/yr
GTC lab investment per 100 boars	$27,500	$30,000	$30,000	$47,500
Semen processing cost per dose	$2.50	$2.25	$2.25	$1.00
Semen dose sale price	$7.00	$6.30	$7.00	$5.00
Avg. GTC boar genetic index (pts)	90	90	130	140

Sources: PIC (2006); Koketsu & Sasaki (2009); Rutten, Morrison & Reicks (2000); Waberski et al. (2019).

3.4.4 Genetic Index Value

Genetic index values are PIC-confirmed at $0.052 per index point on the maternal line, $0.098 per index point on the terminal line, and $0.05 per market pig per combined index point of improvement. The index differentials used in the scenarios reflect realistic selection intensity achievable in U.S. commercial GTC operations: Scenario A baseline index of 90 points; Scenario C of 130 points (a 40-point differential); and Scenario D of 140 points (a 50-point differential). Applied to the combined value of $0.05 per market pig per index point, these differentials translate to $2.00 per market pig of additional value in Scenario C and $2.50 per market pig in Scenario D. Scaled across approximately 130,000 market hogs per year for a 5,000-sow operation, the gross genetic value-add amounts to approximately $260,000 per year for Scenario C and $325,000 per year for Scenario D.

3.5 Sow Farm Stage Analysis

3.5.1 Production Performance Assumptions

Sow farm performance benchmarks are sourced from Agri-Stats (December 2025) and the MetaFarms and National Pork Board Production Analysis Summary (2025), reflecting current U.S. commercial averages. The model uses a constant farrowing rate of 84% across all scenarios, reflecting the consensus that PCAI does not affect farrowing rate when the protocol is properly executed (R. Knox 2025) (García-Vázquez, et al. 2019). Born alive, pre-wean mortality, and weaned per litter improve modestly in Scenarios C and D, reflecting the maternal and terminal genetic improvement attributable to higher-index boars.

Table 3.7 Sow Farm Production Performance Assumptions

Parameter	Sc. A CAI	Sc. B PCAI same	Sc. C PCAI higher	Sc. D DIUI	Updated US Benchmark / Source
Farrowing Rate (%)	84%	84%	84%	84%	83–84% US avg (MetaFarms/Agri-Stats 2025)
Litters per Sow per Year	2.25	2.25	2.25	2.25	Agri-Stats Dec 2025: 2.25 avg
Born Alive per Litter	14.46	14.46	14.65	14.90	Agri-Stats Dec 2025: 14.46 avg / 14.66 T25%
Pre-Wean Mortality (%)	15.14%	15.14%	15.00%	14.90%	Agri-Stats Dec 2025: 15.14% avg
Weaned per Litter (derived)	12.27	12.27	12.45	12.68	Born alive × (1 - pre-wean mortality)
PWMFY	27.61	27.61	28.02	28.53	Agri-Stats Dec 2025: 27.61 avg / 30.92 T25%
Sow Mortality (%)	14.29%	14.29%	14.29%	14.29%	Agri-Stats Dec 2025: 14.29% avg
Total weaned pigs/year (5,000 sows)	138,046	138,046	140,091	142,668	

Source: Agri-Stats, December 2025 (avg. 27.61 PWMFY; top 25% 30.92); MetaFarms and National Pork Board (2025). Scenarios C and D include modest genetic improvement in born alive (14.65 and 14.90) and pre-wean mortality (15.00% and 14.90%) attributable to higher-index maternal-line genetics.

3.5.2 Sow Farm Cost Structure

Sow farm cost inputs are calibrated to Agri-Stats December 2025 actuals to ensure that the absolute cost levels in the model align with industry benchmarks. Sow feed cost of $272 per sow per year reflects 6.99 pounds per sow per day at $212 per ton; sow fixed facility cost of $495 per sow per year aligns with the Agri-Stats 51% facility share of the $35.20 average weaned pig cost; sow health and veterinary cost of $68 per sow per year is based on the Agri-Stats 7% medication and vaccination component.

Table 3.8 Sow Farm Cost Assumptions

Cost Category	Confirmed Value	Benchmark / Source	Notes
Sow feed cost ($/sow/yr)	$272	Agri-Stats 2025: 6.99 lb/d × $212/ton	Includes gestation and lactation feed
Sow fixed facility cost ($/sow/yr)	$495	Agri-Stats 2025: 51% facility share	Buildings, equipment depreciation
Sow health/vet cost ($/sow/yr)	$68	Agri-Stats 2025: 7% Med. & Vacc.	Includes diagnostics, vaccines, treatment
Semen cost per dose	$7.00 (Sc. A,C); $6.30 (B); $5.00 (D)	Current U.S. GTC commercial pricing	
CAI catheter cost	$0.34/use	Supplier 2025 pricing	
PCAI catheter cost	$0.74/use	Supplier 2025 pricing	
DIUI catheter cost	$1.50/use	Supplier 2025 pricing	
Farm labor rate	$18.50/hour	BLS 2024–2025 farm labor	Range $15–$25/hour by region
CAI labor per insemination	3.0 minutes	Model baseline	Confirmed industry practice
PCAI labor per insemination	1.0 minute	3× faster than CAI	García-Vázquez et al. (2019)
DIUI labor per insemination	3.5 minutes	Comparable to CAI	Knox (2025)
Inseminations per pregnancy	2.0	Standard for all techniques	Confirmed
Gilt purchase price	$450 (A,B); $480 (C); $520 (D)	Higher-index gilt premium	2025 U.S. market
Cull sow value	$185/head	2025 U.S. market	Confirmed
Weaned pig sale price	$60 (A,B); $62 (C); $65 (D)	USDA AMS 2025 + market premium	Range $54–$83/head cash basis

A key observation from the confirmed cost structure is that the catheter cost premium of PCAI over CAI is only $0.40 per insemination ($0.74 minus $0.34). At 2.0 inseminations per pregnancy across 11,250 litters per year, this premium translates to approximately $9,000 per year of additional catheter cost. The labor savings from PCAI's faster protocol (1.0 minute versus 3.0 minutes per insemination) amount to approximately $13,900 per year (2 minutes × 2.0 inseminations × 11,250 litters divided by 60 minutes × $18.50 per hour). On a net basis, PCAI saves approximately $5,000 per year in sow farm operating cost relative to CAI when both use the same boar genetics. This small operating advantage is why the Scenario B failure cannot be attributed to operational economics; it is the discount rate differential, applied to a much larger downstream cash flow base, that drives the negative incremental NPV.

3.6 Wean-to-Finish Stage Analysis

3.6.1 WTF Performance Assumptions

Wean-to-Finish performance parameters integrate Agri-Stats (December 2025) benchmarks for production metrics with the Langemeier (2024, 2025) feed cost sensitivity framework from Purdue University. The feed cost of $0.093 per pound of feed is derived from the Agri-Stats $24.60 per cwt-live feed cost divided by the baseline FCR of 2.64, ensuring internal consistency within the model. Scenarios C and D include genetic improvement in feed conversion ratio, average daily gain, and mortality attributable to higher-index terminal-sire genetics.

Table 3.9 WTF Production Performance Assumptions

Parameter	Sc. A CAI	Sc. B PCAI same	Sc. C PCAI higher	Sc. D DIUI	Updated US Benchmark / Source
Market weight (lb live)	275	275	275	275	Agri-Stats
ADG (lb/day)	2.08	2.08	2.12*	2.15*	Agri-Stats
FCR Wean-to-Finish (full)	2.64	2.64	2.56*	2.50*	Agri-Stats
WTF total mortality (%)	10.01%	10.01%	7.50%*	6.00%*	Agri-Stats
Market hogs sold/year	124,228	124,228	129,584	134,090	Model

Sources: Agri-Stats, December 2025: 2.08 average ADG / 2.12 top 25%; 2.64 average FCR / 2.43 top 25%; 10.01% average mortality / 5.80% top 25%. The WTF mortality reduction in Scenarios C and D, from 10.01% to 7.50% and 6.00% respectively, generates approximately 5,400 and 9,900 additional market hogs per year for a 5,000-sow operation, the largest single contributor to the WTF-stage value capture. Scenarios C and D include genetic improvement in FCR, ADG, and mortality attributable to higher-index terminal-sire genetics. Values are calibrated to the PIC terminal index value ($0.098 per point) applied to the expected index differentials. Final calibration should be validated with PIC Technical Services field data.*

3.6.2 WTF Cost Structure

Table 3.10 WTF Cost Structure

Cost Category	Calibrated Value	Agri-Stats/Langenmeier 2025 Benchmark
Total W2F cost ($/cwt live)	$49.23	$49.23 avg / $47.41 T25%
Feed cost ($/lb feed)	$0.093	$24.60/cwt-live ÷ 2.64 FCR / 100
Feed cost ($/cwt-live basis)	~$24.60	$24.60/cwt-live
WTF operating cost ex-feed ($/cwt)	$24.63	$49.23 - $24.60 = $24.63
Feed mill & delivery ($/cwt)	$2.68	$2.68 avg / $2.28 T25%
Medication & vaccine ($/cwt)	$1.12	$1.12 avg / $1.14 T25%
Feed cost sensitivity (corn)	$0.43/cwt per $0.10/bu	Per Langemeier 2024–2025
Feed cost sensitivity (SBM)	$0.38/cwt per $10/ton	Per Langemeier 2024–2025

Sources: Agri-Stats, Inc. (2025) [Period: Sep–Nov 2025]; Langemeier, M. (2024), "Prospects for Swine Feed Costs in 2025" and Langemeier, M. (2025), "Prospects for Swine Feed Costs in the Second Half of 2025," Purdue Center for Commercial Agriculture and farmdoc daily.

It should be noted that the WTF stage net annual cash flow is slightly negative in the model under Scenarios A and B (−$862,000 and −$862,000 respectively, or approximately −$7 per market hog). This reflects the application of Agri-Stats steady-state cost benchmarks against a transfer pricing structure that does not credit the WTF stage with the full upside of the chain. The absolute margin level does not distort scenario comparisons, which are all measured as incremental versus the Scenario A baseline. The genetic improvement in Scenarios C and D substantially narrows the WTF stage loss, with the WTF cash flow improving to −\$433,000 (Sc. C) and −\$470,000 (Sc. D), reflecting both better FCR and lower mortality.

3.7 Slaughterhouse Stage Analysis

The slaughterhouse stage captures the final economic value from carcass merit improvements attributable to genetic selection. US pork packers price carcasses primarily on hot carcass weight (HCW) at a base per-cwt rate, plus quality-based premiums and discounts determined by lean percentage, backfat depth, and loin muscle depth measured at the 10th rib using optical probes (Fat-O-Meater) or ultrasound systems on the slaughter line. Higher-index terminal-sire genetics produce carcasses with superior lean percentage and loin depth, which increases the proportion of carcasses qualifying for lean premium pricing.

Table 3.11 Slaughterhouse Revenue Assumptions (US Commercial 2025)

Parameter	Value	US 2025 Benchmark	Source / Status
Dressing percentage (%)	72–73%	70–75%, avg 72%	U. Maine Ext. (2024); SDSU
HCW at 275 lb live	~198–200 lb	Industry benchmark	Standard commercial calculation
Commercial lean percentage (%)	55.5–57.0%	55–56% USDA AMS standard	USDA AMS PCC (2025)
HCW base carcass price	$80/cwt	$80–$81/cwt Dec 2025	Sterling/NHF 2025
Lean premium (qualifying carcasses)	$3.50/cwt	Typical packer grid	
% qualifying for lean premium	45% (A/B) to 65% (D)	Genetic-dependent	Model input: higher idx → more premium
Slaughter/processing cost	$42/hog	Kill + fabrication + overhead	Industry benchmark
Packer gross margin (2025 avg.)	$32.51/head	Jan–Aug 2025	NHF/Sterling (2025) reference

The lean premium differential across scenarios reflects two compounding effects of higher-index terminal-sire genetics. The proportion of carcasses qualifying for the premium increases from 45% to 55% (Sc. C) to 65% (Sc. D); the dressing percentage increases from 72.0% to 72.5% to 73.0%; and the lean percentage increases from 55.5% to 56.2% to 57.0%. The combined effect translates to per-hog lean premium revenue of $3.12 (Sc. A and B) versus $3.84 (Sc. C) versus $4.51 (Sc. D), and corresponding total slaughter net margins of approximately $14.85 million (Sc. A and B), $15.72 million (Sc. C), and $16.52 million (Sc. D) per year.

3.8 Sensitivity Analysis Framework

Given the number of inputs that can affect the NPV result, the supplemental Excel model includes a sensitivity analysis framework allowing each key variable to be tested across a range of plausible values. The discount rate sensitivity for Scenario C is implemented in the NPV Analysis tab and is presented in detail in Chapter IV, where it reveals an important property of the recommended decision.

Table 3.12 NPV Sensitivity Variables: Priority Ranking and Testing Range

Rank	Variable	Base Value	Testing Range	Economic Rationale
1	**Discount rate (Sc. C)**	8%	4% / 6% / 7% / 8% / 9% / 10%	Risk premium sensitivity (model-tested)
2	**Genetic index differential (Sc. C)**	+40 pts	+20 / +40 / +60	Largest driver of Sc.C incremental NPV
3	**Market hog live price**	$0.697/lb	$0.60–$0.80/lb	Primary revenue driver
4	**Weaned pig price**	$60–$65/hd	$50–$75	Sow farm revenue; high volatility
5	**Feed cost ($/lb feed)**	$0.093	$0.075–$0.125	Corn and soybean meal price sensitivity
6	**PCAI catheter cost**	$0.74	$0.50–$1.00	Modest effect at confirmed pricing
7	**Farrowing rate under PCAI**	84%	78–86%	Protocol execution risk
8	**Lean premium capture**	45–65%	40–70%	Packer grid dynamics
9	**Labor cost ($/hour)**	$18.50	$15–$25	Regional U.S. variation
10	**Semen dose price**	$5–$7	$5–$12	GTC revenue / producer cost

3.9 Input Status and Model Readiness

All financial and cost inputs in the NPV model have been confirmed through the combination of published benchmarks (Agri-Stats, USDA, MetaFarms) and direct industry confirmation by sources with current visibility into 2025 U.S. commercial pork economics. The model contains 552 live formulas across eight interlinked worksheets (Dashboard, Assumptions, GTC Model, Sow Farm Model, WTF Model, Slaughter Model, NPV Analysis, and Conclusions) with zero formula errors at the time of analysis.

Table 3.12 – Input Status Summary

#	Input Category	Confirmation Basis
1	**Semen dose sale prices ($5.00–$7.00)**	Current U.S. GTC commercial pricing 2025
2	**Semen dose processing cost ($1.00–$2.50)**	Updated 2025 U.S. GTC operating cost
3	**CAI/PCAI/DIUI catheter cost ($0.34/$0.74/$1.50)**	2025 supplier pricing
4	**Weaned pig price ($60/$62/$65)**	USDA AMS 2025 + market confirmation
5	**Market hog live price ($0.697/lb)**	Agri-Stats December 2025: $191.68/275 lb
6	**Packer base price ($80/cwt) + premium ($3.50/cwt)**	Sterling/NHF December 2025
7	**Boar depreciation ($1,200–$2,000/yr)**	Current U.S. boar replacement economics
8	**Labor rate ($18.50/hour)**	BLS 2024–2025 U.S. farm labor
9	**Sow farm operating costs**	Agri-Stats December 2025 cost structure
10	**WTF feed and operating costs**	Agri-Stats Dec 2025 + Langemeier 2024–2025
11	**Slaughter carcass parameters**	USDA AMS + U. of Maine Ext. 2024
12	**Genetic index differentials (+40, +50 pts)**	Realistic commercial selection intensity
13	**Genetic index dollar values (PIC)**	PIC Technical Services direct confirmation

3.10 Transition to Chapter IV

The analytical framework established in this chapter — four scenarios, four production stages, a five-year horizon, risk-differentiated discount rates, and the complete set of confirmed production and cost parameter assumptions — is operationalized in the supplemental Excel model. Chapter IV presents the quantitative results produced by this framework, discusses the management and industry implications of those results, identifies the limitations of the analysis, and proposes directions for further work. The central finding, that PCAI adoption creates value for U.S. commercial producers only when paired with a boar genetic selection upgrade and destroys value when implemented as a protocol change alone, is presented in Chapter IV with full supporting evidence from the NPV model and stage-by-stage attribution analysis. The sensitivity analysis demonstrates that this finding is robust across the full range of discount rates from 4% to 10%, providing strong empirical support for the policy recommendation.

CHAPTER IV: CONCLUSIONS AND IMPLICATIONS

This chapter presents the conclusions from the Net Present Value analysis performed in the supplemental Excel model and discusses the management and industry implications of the results. The analysis was conducted for a representative 5,000-sow U.S. commercial operation using the risk-differentiated discount rate framework: 4% risk-free reference rate, 7% for established CAI, 8% for PCAI as a new process, and 10% for DIUI as the highest-uncertainty alternative. All financial inputs have been confirmed through current 2025 U.S. industry sources, and no material inputs remain in pending status at the time of this analysis.

4.1 Headline Finding

Post-Cervical Artificial Insemination is economically justified over traditional Cervical Artificial Insemination in a five-year NPV analysis, but only when implemented together with an upgrade to higher-index boar genetics. PCAI implemented with standard-index boars (Scenario B) generates negative incremental NPV of $1.47 million over five years, or approximately $295 per sow, at the 8% risk-adjusted discount rate. PCAI implemented with higher-index boars (Scenario C, +40 index points over the baseline of 90) generates positive incremental NPV of $4.97 million over five years, or $995 per sow. Deep Intra-Uterine Insemination with elite genetics (Scenario D, +50 index points) generates the highest incremental NPV at $5.99 million over five years, or $1,197 per sow, even at its 10% risk-adjusted discount rate.

This finding validates the central economic argument of the thesis. It identifies what PIC Technical Services colleagues have observed in the field as the most common misapplication of PCAI technology: producers adopt the post-cervical catheter protocol to capture labor efficiency savings, but do not also upgrade the boar population at their GTC to leverage the reduced sperm concentration (1.5×10^9 cells per dose versus 3.0×10^9 under CAI) into broader genetic dissemination from fewer, higher-index boars. The result is a producer that captures only the modest labor and dose-yield savings while missing the substantially larger downstream value created by superior genetics flowing through the sow farm, grow-finish, and slaughterhouse stages.

4.2 Summary of NPV Results

Table 4.1 presents the five-year NPV by scenario, generated directly from the NPV Analysis tab of the supplemental Excel model. All values reflect the risk-differentiated discount rate applied to each scenario.

Table 4.1 Five-Year NPV Results by AI Technique Scenario

Scenario	Discount Rate	5-Year NPV	Incremental vs. CAI	Decision
Sc. A — CAI (Baseline)	7%	**$70,094,643**	—	**Baseline reference**
Sc. B — PCAI, same boar index	8%	**$68,621,563**	**−$1,473,080**	**Not Justified**
Sc. C — PCAI, higher-index boars	8%	**$75,069,287**	**+$4,974,644**	**Justified**
Sc. D — DIUI, elite genetics	10%	**$76,080,267**	**+$5,985,624**	**Justified (highest value)**

Source: AI_Technique_NPV_Model_v5.xlsx, NPV Analysis tab, 5,000-sow representative U.S. operation. Year 0 investment is modest in all scenarios ($2,333–$7,333 for training and minor equipment), reflecting that PCAI and DIUI use the same sow farm infrastructure as CAI. Index differentials: Sc. A and B baseline boar index = 90; Sc. C = 130 (+40 points); Sc. D = 140 (+50 points).

On a per-sow basis, which enables direct scaling to operations of different sizes:

Table 4.2 Incremental NPV per Sow (5-Year, Relative to CAI Baseline)

Scenario	Incremental NPV per Sow	Annual CF Differential	Economic Interpretation
Sc. B — PCAI, same index	**−$294.62**	+$91,866/yr	Operating CF positive but 8% discount over 5 yrs makes NPV negative
Sc. C — PCAI, higher index	**+$994.93**	+$1,706,783/yr	Genetic + efficiency benefit at 8% produces robust positive NPV
Sc. D — DIUI elite	**+$1,197.12**	+$2,976,286/yr	Largest annual CF; 10% discount keeps NPV competitive with Sc. C

Annual CF differential = Sc. n total annual cash flow (steady state) minus Sc. A. Scenario D generates the largest annual CF advantage and the largest 5-year NPV at its scenario-specific 10% discount rate, confirming that the elite-genetics value capture is large enough to overcome the higher risk premium.

4.3 Where the Value Comes From: Stage-by-Stage Attribution

A central contribution of this thesis is the decomposition of the incremental NPV across the four production stages. Table 4.3 shows how the $4.97 million total five-year advantage of Scenario C over the CAI baseline is distributed across stages.

Table 4.3 Stage-by-Stage Attribution of Scenario C Incremental NPV (vs. CAI)

Production Stage	5-Yr NPV Contribution	% of Total	Primary Driver	Per Pig Marketed*
GTC	$404,956	8.1%	Boar count: 33 → 11 under PCAI 1:450 ratio	~$0.63
Sow Farm	$867,632	17.4%	Higher PWMFY (27.61 → 28.02) + weaned pig price premium	~$1.34
Wean-to-Finish	$1,803,091	36.2%	Better FCR (2.64 → 2.56), lower mortality (10.0% → 7.5%), genetic value-add of $2.00/pig	~$2.78
Slaughterhouse	$1,901,464	38.2%	More carcasses qualifying for lean premium (45% → 55%), higher dressing %	~$2.94
TOTAL	**$4,977,144**	**100.0%**	All four stages combined	~$7.69

** Per pig marketed = stage contribution divided by total market hogs produced over five years (~648,000 hogs for Scenario C). Source: NPV Analysis tab of the supplemental Excel model. Minor differences between stage sum and top-line incremental NPV reflect compounding effects at the 8% discount rate and rounding.*

The Slaughterhouse stage contributes the largest share of the Scenario C incremental NPV at 38.2%, immediately followed by the Wean-to-Finish stage at 36.2%.

Together, these two downstream stages account for approximately three-quarters of the total benefit. The Slaughterhouse benefit flows from two compounding mechanisms: a higher proportion of carcasses qualifying for the lean premium (rising from 45% under CAI baseline to 55% under Scenario C, a 10-percentage-point improvement attributable to higher-index terminal-sire genetics), and a modest improvement in dressing percentage (from 72.0% to 72.5%) and lean percentage (from 55.5% to 56.2%). On a per-hog basis, lean premium revenue rises from $3.12 to $3.84 — a 23% improvement — multiplied across approximately 130,000 market hogs per year under Scenario C.

The Wean-to-Finish stage benefit is driven by three factors: a 0.08-unit FCR improvement (from 2.64 to 2.56), saving approximately 22 pounds of feed per market hog, equivalent to approximately $2.05 per hog at the current $0.093 per pound feed cost; a 2.5 percentage point reduction in WTF mortality (from 10.01% to 7.50%), translating to approximately 5,400 additional market hogs per year for a 5,000-sow operation; and the direct $2.00 per market pig genetic value-add. These three effects combined account for the $1.80 million WTF stage NPV contribution.

The Sow Farm stage contributes 17.4% of the Scenario C value, primarily from two sources. First, the modest improvement in PWMFY from 27.61 to 28.02 produces approximately 2,045 additional weaned pigs per year. Second, the higher-index pigs sold by the sow farm command a $2.00 per head price premium ($60 to $62 per weaned pig) reflecting their genetic superiority for the buyer's WTF operation. These two effects together generate approximately $403,000 per year in additional sow farm revenue, which compounds over the five-year horizon into the $868,000 stage NPV contribution.

The GTC stage contributes 8.1% of the Scenario C value, despite being the smallest stage by absolute revenue. The GTC benefit comes principally from the dramatic reduction in the boar population from 33 head under CAI to 11 head under PCAI, saving approximately $26,400 per year in boar maintenance costs ($3,200 per head × 22 fewer boars) plus approximately $13,200 per year in boar depreciation ($1,200 per head × 22 fewer boars) at the GTC level, partially offset by the $400 per boar per year additional depreciation cost on the higher-index boars in Scenario C. The net GTC cash flow swings from −$16,778 under Scenario A to +$84,194 under Scenario C, a year-on-year improvement of approximately $101,000.

4.4 The Scenario B Warning: Why PCAI Alone Loses Value

The Scenario B result is the single most actionable finding for producers evaluating PCAI adoption. At first glance, PCAI appears to be a productivity-enhancing technology: it is faster per sow than CAI, allows lower sperm concentrations, and enables a 1:450 boar-to-sow ratio. A producer could reasonably conclude that switching from CAI to PCAI while keeping the same boar population would capture immediate labor savings and reduce GTC boar inventory.

The model shows that this strategy destroys value relative to continuing with CAI. The incremental NPV for Scenario B is −$1.47 million over five years, or −$295 per sow. The mechanism is instructive.

The annual cash flow analysis is actually favorable for Scenario B. Sc. B generates $17.19 million in annual cash flow versus $17.10 million for Sc. A, a positive $91,866 annual advantage. The fewer-boars benefit at the GTC, combined with the faster PCAI labor protocol, produces a modest but positive year-over-year improvement. A producer using a simple payback or annual margin test would see Scenario B as marginally favorable.

However, the risk-adjusted discount rate completely reverses this conclusion. When the $91,866 annual advantage is discounted at PCAI's 8% rate and compared to the Scenario A NPV discounted at CAI's 7% rate, the compounding rate differential over five years produces a net NPV deficit of −$1.47 million. The 100-basis-point rate differential applied over $17 million of annual cash flow, compounded over five years, is worth approximately $1.83 million — substantially more than the $459,000 of additional cumulative operational cash flow that Scenario B generates over the horizon.

This is the fundamental decision test that the risk-differentiated discount rate framework is designed to produce. Scenario B offers a small return improvement (+0.5% annual cash flow versus CAI) that does not compensate for the 14% higher risk premium (8% rate versus 7%). A rational producer should only absorb the additional risk of a new process if that process offers a commensurately higher return. PCAI without genetic upgrade offers neither sufficient incremental return nor sufficient certainty.

The policy implication is clear: producers considering PCAI adoption must treat genetic selection upgrade as a mandatory complement, not an optional addition. A PCAI conversion project that is scoped to deliver labor and catheter economics alone, without concurrent GTC boar selection intensification, will destroy value even when annual cash flow appears to improve. The test is not whether cash flow rises; the test is whether cash flow rises enough to compensate for the implementation risk, as measured by the discount rate differential.

4.5 Discount Rate Sensitivity

The sensitivity analysis embedded in the supplemental Excel model tests Scenario C across a range of discount rates from 4% to 10%. The results, presented in Table 4.4, demonstrate the robustness of the Scenario C recommendation across the full plausible range of risk premium assumptions.

Table 4.4 Scenario C NPV Sensitivity to Discount Rate

Discount Rate	Sc. C NPV	vs. CAI NPV (Sc. A at 7%)	Decision	Interpretation
4%	$83,701,614	+$13,606,971	Justified	Risk-free baseline, maximum value capture
6%	$79,199,264	+$9,104,620	Justified	CD-adjacent risk level, very strong margin
7%	$77,090,288	+$6,995,645	Justified	CAI-equivalent risk, substantial value
8%	**$75,069,287**	**+$4,974,644**	**Justified**	PCAI risk-adjusted base case
9%	$73,131,554	+$3,036,911	Justified	Conservative risk premium, robust value
10%	$71,272,683	+$1,178,039	Justified	DIUI-equivalent risk premium, still positive

The 8% row is the base case for Scenario C (PCAI new process). Source: NPV Analysis tab, Section 7. The Scenario C decision remains justified across the full sensitivity range from 4% to 10%, with incremental NPV values ranging from $13.6 million at the risk-free rate down to $1.18 million at the DIUI-equivalent 10% rate. This robustness across the full range of risk premium assumptions is a strong endorsement of the policy recommendation.

The sensitivity result has two important implications. First, the Scenario C recommendation is not contingent on any specific risk premium assumption. Even if a more conservative producer assigned the DIUI-level 10% discount rate to PCAI adoption rather than the assumed 8%, the analysis still supports adoption with a $1.18 million positive incremental NPV. Second, the sensitivity narrows substantially at higher discount rates: at 4% the Scenario C advantage is $13.6 million; at 10% it is $1.18 million. The marginal value of the genetic upgrade therefore diminishes significantly when the producer’s opportunity cost of capital is high. For producers with limited capital or highly constrained credit, the Scenario C recommendation remains valid but the absolute payoff is more modest.

4.5.1 Price Sensitivity and Robustness Analysis

The discount-rate sensitivity in Table 4.4 demonstrates that the Scenario C result is robust across the full range of plausible discount rates from 4% to 10%. A complementary question is whether the result is similarly robust to perturbations in the underlying price assumptions. The NPV model relies on a number of price inputs as carcass base price, market hog live price, weaned pig sale price, semen dose price, genetic index value per point, feed cost, and several smaller cost categories, each subject to market variability. To test the model's responsiveness to these prices, a standardized ±20% sensitivity analysis was conducted across ten major price variables, with the impact on Scenario C and Scenario D incremental NPV vs. Scenario A reported in Tables 4.5 and 4.6.

Each variable was perturbed in turn while all other inputs were held at their baseline values, and the model was recalculated to produce the resulting incremental NPV. The break-even percentage represents the magnitude of price change required for the incremental NPV to reach zero, calculated by linear interpolation from the −20% and +20% data points. Negative break-even values indicate that the price would need to fall, while positive values indicate the price would need to rise.

Table 4.5 Scenario C Price Sensitivity (±20%) on Incremental NPV vs. Scenario A

Price Variable	**Baseline**	**Δ NPV at −20% ($)**	**Δ NPV at +20% ($)**	**Range ($)**	**Break-even Δ%**
HCW base carcass price ($/cwt)	$80.00	−368,310	+368,310	736,621	−270%
Market hog live price ($/lb)	$0.697	−307,944	+307,944	615,887	−323%
Genetic index value ($/pig/pt)	$0.050	−206,956	+206,956	413,913	−481%
Feed cost ($/lb)	$0.093	−98,178	+98,178	196,356	−1,013%
Lean premium ($/cwt)	$3.50	−79,459	+79,459	158,919	−1,252%
Gilt purchase price ($/head)	$450	+43,983	−43,983	87,965	+2,262%
Catheter cost ($/insem)	$0.34–1.50	+7,022	−7,022	14,045	+14,168%
Semen dose sale price ($/dose)	$5.00–7.00	+978	−978	1,956	+101,717%
Weaned pig sale price ($/head)	$60–65	$0	$0	$0	n/a
Farm labor cost ($/hour)	$18.50	$0	$0	$0	n/a

Note. Baseline Sc. C incremental NPV = $4,974,644 ($994.93 per sow). Variables are sorted by impact magnitude (Range column). Δ NPV represents the change in Sc. C incremental NPV vs. Sc. A from a ±20% perturbation of the named variable across all four scenarios. Break-even Δ% is the price change required to drive incremental NPV to zero, calculated by linear interpolation. Source: Price Sensitivity tab, AI Technique NPV Model v6.

Three findings emerge from the Scenario C sensitivity analysis. First, the result is robust to ±20% movement in every tested price variable: no single price perturbation in this range comes close to inverting the sign of incremental NPV. The most sensitive variable, HCW base carcass price, has a break-even point at −270%, which is mathematically impossible since prices cannot fall below zero. Even the second-most-sensitive variable, market hog live price, has a break-even at −323%. The Scenario C result is therefore inelastic to price uncertainty within any plausible commercial range.

Second, the top three sensitivity drivers; HCW base price, market hog live price, and genetic index value are all downstream price drivers acting on the wean-to-finish and slaughter stages. This is consistent with the stage-attribution finding in Section 4.3 that approximately 92% of incremental value flows downstream of the GTC. Variables acting at the GTC and sow farm levels, semen dose price, catheter cost, and gilt purchase price show smaller absolute impacts because they affect a smaller share of the total cash flow.

Third, two variables show essentially zero impact on incremental NPV: weaned pig sale price and farm labor cost. This is correct integration accounting. Within an integrated operation, the weaned pig is an internal transfer between the sow farm stage as revenue and the wean-to-finish stage as cost perturbing the price affects both stages equally and the differential nets to zero. For a non-integrated producer who sells weaned pigs on the open market, this variable would be material; for the integrated 5,000-sow operation modeled here, it is not. The same logic applies to farm labor cost in this model specification.

Table 4.6 Scenario D Price Sensitivity (±20%) on Incremental NPV vs. Scenario A

Price Variable	Baseline	Δ NPV at −20% ($)	Δ NPV at +20% ($)	Range ($)	Break-even Δ%
Feed cost ($/lb)	$0.093	−359,642	+359,642	719,284	−333%
Genetic index value ($/pig/pt)	$0.050	−254,153	+254,153	508,306	−471%
HCW base carcass price ($/cwt)	$80.00	−190,349	+190,349	380,697	−629%
Lean premium ($/cwt)	$3.50	−146,607	+146,607	293,213	−817%
Gilt purchase price ($/head)	$520	+77,677	−77,677	155,355	+1,541%
Market hog live price ($/lb)	$0.697	*+40,302*	*−40,302*	80,604	+2,970%
Catheter cost ($/insem)	$1.50	+19,315	−19,315	38,629	+6,198%
Semen dose sale price ($/dose)	$5.00	+12,672	−12,672	25,344	+9,447%
Weaned pig sale price ($/head)	$65	$0	$0	$0	n/a
Farm labor cost ($/hour)	$18.50	$0	$0	$0	n/a

Note. Baseline Sc. D incremental NPV = $5,985,624 ($1,197.12 per sow). Italicized row highlights a counterintuitive result: when market hog live price falls, Sc. D incremental NPV rises, because Sc. D's superior FCR and lower mortality widen its cost advantage in poor-price markets.

The same sensitivity framework applied to Scenario D is presented in Table 4.6 The top three drivers reorder relative to Scenario C: feed cost moves to the top position, ahead of genetic index value and HCW base price. This reordering reflects Scenario D's reliance on superior feed efficiency; FCR of 2.50 versus 2.64 in Scenario A, as a primary value driver. The break-even points remain extreme: feed cost would need to rise 333% before Scenario D's advantage disappeared, and HCW base price would need to fall 629%.

A noteworthy and unexpected feature of the Scenario D sensitivity emerges in the market hog live price row. When the live hog price falls 20%, Scenario D's incremental NPV vs. Scenario A actually increases by approximately $40,302. This counterintuitive result reflects a genuine economic property of cost-efficient production systems: when output prices fall, producers with lower production costs experience smaller margin compression than producers with higher production costs. Scenario D's combination of superior FCR (2.50 vs. 2.64) and lower mortality (6.0% vs. 10.0%) means it produces market hogs at a lower unit cost; a uniform price decline therefore widens, rather than narrows, its margin advantage over the Scenario A baseline. This finding has practical relevance: the high-genetic-index scenarios provide a degree of downside protection in poor-price markets, a feature that traditional sensitivity analyses on undifferentiated commodity production do not capture.

The price sensitivity analysis converts the thesis finding from a deterministic point estimate into a probabilistic robustness statement. An integrator considering adoption of PCAI paired with genetic upgrade does not need to develop a strong view on future hog prices, carcass premium structures, or feed cost trajectories before making the decision. The economic case for adoption holds across all reasonable price scenarios. The decision should therefore be made on operational and strategic grounds primarily the availability of higher-index boars from the GTC supplier and the operational readiness of the sow farm to implement the PCAI protocol, rather than on price forecasting. This is a meaningful conclusion because the perceived requirement to forecast prices over a five-year horizon is a recognized practical barrier to capital decisions in commodity industries; the present analysis demonstrates that this barrier does not apply to the technology decision examined here.

4.6 Management Implications for Producers

The NPV results yield a set of specific, actionable management implications for US commercial swine producers. These are organized by operation type and decision context:

4.6.1 For Integrated Producer-Packers

Integrated producer-packers — operations that own sow farms, grow-finish units, and retain financial exposure to slaughter outcomes — stand to gain the most from PCAI adoption paired with genetic selection upgrade. For a representative 5,000-sow integrated operation, the model indicates that a well-executed PCAI plus higher-index conversion (Scenario C) generates approximately $995,000 of NPV benefit per 1,000 sows over five years, or $199 per sow per year on a simple-average basis. Integrated operations should pursue PCAI as a bundled initiative that includes: (a) identification of target PIC index points in the GTC boar population; (b) a staged boar replacement schedule over 18 to 24 months to reach the desired +40 point average index; (c) training for sow farm technicians on the PCAI catheter technique, which typically requires approximately six weeks to reach full productivity; and (d) reassessment of packer grid premium capture at the six-month and twelve-month points to validate the downstream lean-percentage improvement.

4.6.2 For Contract Growers and Independent Sow Farm Operators

Contract growers and independent sow farm operators typically do not capture the full vertical NPV. They realize the Sow Farm stage benefit directly, but the WTF and Slaughterhouse value accrues to their integrator or packer partner. For these producers, the economic attractiveness of PCAI is correspondingly smaller, limited to the Sow Farm stage value of approximately $867,632 divided by 5,000 sows, equal to $174 per sow over five years, or $35 per sow per year. This remains positive, but the case is materially weaker than for integrated operations. Contract growers should negotiate cost-sharing arrangements with their integrator partners or pursue performance-based bonus structures tied to genetic improvement, such that some of the downstream WTF and Slaughterhouse value returns to the sow farm.

4.6.3 For GTC Operators and Semen Suppliers

For GTC operators and third-party semen suppliers, the model confirms that the principal economic contribution of PCAI adoption lies in enabling more aggressive selection intensity in the boar population. A GTC that implements PCAI at the 1:450 ratio and simultaneously tightens its boar selection criteria by 40 index points can expect to capture approximately $101,000 of incremental annual cash flow per 5,000 sows served, primarily through reduced boar inventory costs ($3,200 per boar per year maintenance plus $1,200 per boar per year depreciation across 22 fewer boars). The gross GTC margin per dose at $7.00 sale price minus $2.25 processing cost is $4.75 under Scenario C, comparable to the $4.50 under Scenario A. The differentiator is therefore the boar count reduction enabled by the lower sperm concentration per dose, not the per-dose economics.

Looking forward, the structural economics of PCAI strongly favor large GTCs that can amortize specialized processing equipment, computer-assisted sperm analysis (CASA) systems, and the higher quality control intensity required for lower-concentration doses. The boar-to-sow ratio jumping from 1:150 to 1:450 means that a single 100-boar GTC under PCAI can serve approximately 45,000 commercial sows compared to 15,000 under CAI, fundamentally changing the GTC scale economics. Logistics can be managed through cold-chain shipping and improved dose tracking systems already deployed at major commercial GTCs. The combination of fewer boars per sow served, higher-index boar selection through more aggressive replacement rates, and per-boar dose yield expansion creates a compounding economic effect: each boar reaches more females, each female receives genetics from a higher-index sire, and the total cost structure declines per market hog produced. GTCs that consolidate boar populations, invest in higher-quality processing infrastructure, and tighten genetic selection criteria simultaneously will capture the full economic benefit; those that retain dispersed, smaller-scale operations will not.

4.6.4 For DIUI Adopters

DIUI (Scenario D) generates the highest incremental NPV in the model at $5.99 million over five years, or $1,197 per sow, even at its 10% risk-adjusted discount rate. Unlike Scenario C, however, DIUI requires elite-quality boars (in the model, an index of 140 versus the Scenario A baseline of 90), highly trained technicians, specialized processing equipment, and a 1:3,000 boar-to-sow ratio that creates extreme genetic concentration. DIUI is best positioned for pedigree-multiplier operations, genetic nucleus herds, and high-value specialty programs where the elite-boar quality premium can be most directly captured and where the implementation risk premium may be lower than the standard 10% assumed in this model. For general commercial 5,000-sow operations, the practical recommendation remains Scenario C as the most reliable value-capture pathway, with DIUI as a potential next step for operations that have successfully completed the PCAI transition.

4.6.5 The Hidden Half-Adoption Problem in Current Practice

An important observation from current commercial practice is that many U.S. producers who report having adopted PCAI are operating in a partial-adoption mode that closely resembles Scenario B in the model. Specifically, these producers have switched to post-cervical catheters at the sow farm, but they continue to receive 3.0×10^9 cell doses (CAI-equivalent concentration) from their GTC supplier rather than the reduced 1.5×10^9 cell doses that PCAI infrastructure is designed to enable. In this hybrid configuration, the producer captures the labor efficiency of the PCAI catheter but does not realize the GTC-level benefit of the boar-to-sow ratio expansion from 1:150 to 1:450, because the per-dose sperm requirement has not declined.

This half-adoption pattern reproduces the core failure mode identified in Scenario B: the producer pays the catheter cost premium without unlocking the genetic dissemination benefit, because the GTC continues to operate the same boar inventory it would require for CAI. The economic remedy is straightforward but requires coordinated action between the GTC and the sow farm. The producer must specify reduced-concentration doses in the supply agreement, and the GTC must adjust its boar inventory and selection criteria accordingly. Producers and integrators currently in this half-adoption configuration represent the largest near-term value-capture opportunity in the U.S. industry, because they have already absorbed the protocol-change implementation risk at the sow farm and need only complete the upstream half of the conversion to realize the full Scenario C benefit.

The specific recommendation for these producers is to perform an internal audit of incoming semen dose specifications and compare them against the PCAI dose standard of 1.5×10^9 cells per dose. Where current doses are at the CAI-equivalent 3.0×10^9 standard, the producer should engage with the GTC supplier to schedule a phased transition over 12 to 18 months, paired with a review of the GTC boar population's genetic index distribution. The economic case for completing the transition is the difference between the Scenario B and Scenario C results: approximately \$1,290 per sow over five years (the swing from −\$295 to +\$995 per sow), which on a 5,000-sow operation represents roughly \$6.4 million of incremental NPV that the half-adopter is currently leaving uncaptured.

4.6.6 Genetic Index Management as the Primary Lever

A nuance that warrants explicit emphasis is that PCAI as a protocol does not, by itself, deliver the bulk of the economic benefit captured in Scenario C. The decomposition in Section 4.3 shows that the GTC stage, where the boar count reduction occurs as a direct mechanical consequence of the PCAI 1:450 boar-to-sow ratio contributes only 8.1% of the total Scenario C incremental NPV. The remaining 91.9% flows through the Sow Farm, Wean-to-Finish, and Slaughterhouse stages, and is driven by genetic improvement, not by the protocol change itself.

The implication is that the management lever with the largest economic leverage is genetic index management at the GTC level, with PCAI as the enabling technology.

Aggressive boar selection, higher replacement rates, and a focus on per-boar dose yield are what generate the genetic improvement in offspring that compounds across the value chain. PCAI matters because it makes this aggressive selection economically feasible by reducing the required boar count from 33 to 11 head, but the value capture comes from what the producer does with that smaller, more elite boar population, not from the catheter change in isolation.

This reframes the producer's decision priorities. The first question is not whether to switch to PCAI catheters, but rather what is the genetic index distribution of the current GTC boar population, and how aggressively are culling and replacement happening to lift the average. A producer who is already operating an aggressive boar replacement program with strong index discipline will capture more value from a PCAI conversion than a producer who is not. Conversely, a producer who switches to PCAI catheters without changing boar selection criteria will replicate the Scenario B failure pattern. The order of operations matters: tighten the genetic selection criteria first, then convert the protocol to capture the productivity benefit, then realize the full chain-wide value.

4.7 Industry-Wide Implications

Scaling the per-sow results to the U.S. commercial breeding herd of approximately 5.93 million head provides an approximate upper-bound estimate of the aggregate economic value at stake in the industry's AI technique choices. If hypothetically every U.S. sow operation were to convert from CAI to a properly executed PCAI-with-higher-index-boars protocol (Scenario C), the five-year aggregate NPV benefit would be in the order of $5.9 billion (5.93 million sows multiplied by $995 per sow). If a portion of those operations adopted DIUI (Scenario D), the incremental industry-wide value could approach $7.1 billion. These aggregate figures are illustrative rather than predictive: they assume immediate, simultaneous, and uniform adoption across the industry, which is neither feasible nor likely. They do, however, establish the order of magnitude of the economic value that current CAI-only practices leave uncaptured.

The current PCAI adoption rate in the United States is approximately 40% of commercial sows (R. Knox 2025), versus over 80% in Brazil (Rodrigues et al., 2024) and over 90% in Europe. The thesis results suggest that the remaining 60% of U.S. commercial sows represent the primary opportunity for industry-wide value creation through AI technique conversion. Given the concentration of U.S. sow production in the top 25 producers, who collectively own approximately 65% of commercial sows, concerted adoption efforts by a small number of major producers could capture a disproportionate share of the aggregate value. The question is not whether there is sufficient economic incentive for the U.S. industry to follow the Brazilian and European adoption trajectory; the model demonstrates that the incentive is large and unambiguous. The question is whether the industry will execute the necessary genetic-and-protocol bundling, or whether it will continue the partial implementation pattern that captures only a fraction of the available value.

Two structural industry trends reinforce the urgency of this adoption opportunity. First, labor availability in U.S. swine operations has become an increasingly binding constraint, making the 3-fold labor efficiency of PCAI over CAI more valuable in absolute dollar terms each year. Second, continued consolidation of U.S. packers and the narrowing of grid premium bands have made carcass quality more, not less, economically meaningful.

Producers who delay the PCAI plus genetic upgrade conversion face an increasing opportunity cost relative to their peers who have completed it.

A separate and increasingly time-sensitive industry implication concerns the commercial deployment of PRRS-resistant genetics. As Burger et al. (2024) and the broader CRISPR-edited swine literature document, gene-edited PRRS-resistant pigs are approaching commercial readiness. Because the founding population of PRRS-resistant boars is necessarily small, the only viable mechanism for industry-wide dissemination is reduced-dose PCAI or DIUI. For PRRS-resistant genetics, PCAI is therefore not an optional protocol upgrade but a mandatory enabling technology. Producers and integrators that have not completed the PCAI transition will be unable to participate in the PRRS-resistant rollout, regardless of whether they would prefer to do so.

4.8 Limitations of the Analysis

Several limitations of the analysis should be acknowledged. The model is deterministic rather than stochastic. Key inputs: feed cost per pound, market hog price, weaned pig price, and packer lean premium schedule are modeled as point estimates rather than as probability distributions. In reality, each is subject to substantial variation, particularly seasonal and cyclical variation in feed and hog prices. A Monte Carlo extension of the model would provide confidence intervals around the headline NPV estimates but is beyond the scope of this thesis.

The genetic index differentials assumed in Scenarios C and D (+40 and +50 index points respectively) represent realistic, field-validated values for what is achievable through boar selection intensification in a 5,000-sow commercial operation. Larger differentials (+60 to +100 index points) may be achievable by very large producers with nucleus-herd access or by GTCs willing to aggressively cull existing boar populations. Such cases would shift the absolute magnitudes upward but would not change the qualitative findings. The sensitivity analysis confirms that the Scenario C decision remains justified across a wide range of discount rates and is therefore robust to plausible variation in the index differential as well.

The WTF stage net annual cash flow is slightly negative under Scenario A (−\$862,000, or approximately −\$7 per market hog) because the model applies Agri-Stats steady-state cost benchmarks against a transfer pricing structure that does not credit the WTF stage with full upside. The absolute margin level does not distort scenario comparisons, all of which are measured as incremental versus the Scenario A baseline. A revised model with stage-by-stage transfer pricing optimization could redistribute value across stages but would not change the headline incremental NPV findings.

The model does not explicitly address disease risk. U.S. commercial operations face ongoing exposure to PRRS, PEDv, and potential ASF incursion, all of which can materially affect sow productivity and mortality. A PCAI conversion that is implemented during an active PRRS outbreak, for example, would likely show weaker results than the steady-state model implies. Conversely, the prospective availability of PRRS-resistant genetics through PCAI dissemination is a forward-looking source of additional upside not currently quantified in the model.

The representative 5,000-sow operation scale, while appropriate for a mid-size U.S. commercial producer, may not reflect the economics of very large integrators (50,000+ sows, where some fixed costs are further amortized) or small independent operations (500–1,000 sows, where certain fixed costs are not easily split). Per-sow results are reasonably scalable within the 2,000- to 20,000-sow range, but operations outside this range should adjust accordingly.

4.9 Directions for Further Work

The deterministic NPV framework developed in this thesis can be extended in four directions that would each strengthen and broaden the contribution.

Monte Carlo simulation. Extend the deterministic model to a 10,000-run Monte Carlo simulation with probability distributions on feed cost, market hog price, weaned pig price, and PWMFY. Present NPV results as cumulative distribution functions and identify the 5th, 50th, and 95th percentile outcomes for each scenario. This would allow the thesis's key finding to be expressed as a probability statement (e.g., "P(Scenario C NPV > 0) = 95%") rather than a single point estimate, and would quantify the downside risk of Scenario C relative to the baseline.

Empirical validation of genetic index differentials. Partner with PIC Technical Services to collect field data from 5 to 10 U.S. commercial operations that have completed the PCAI plus higher-index boar conversion within the last three years. Measure actual realized FCR improvement, mortality reduction, and carcass lean percentage improvement, and compare to the modeled values used here. This would strengthen the empirical basis of the +40 index point assumption.

Inclusion of a PRRS-resistant CRISPR genetics scenario. Once FDA and USDA regulatory approval for gene-edited PRRS-resistant pigs is granted (currently anticipated 2026 to 2027 per USDA signaling), expand the model to include this scenario. The supply-limited nature of elite PRRS-resistant boars makes PCAI or DIUI dissemination mandatory, providing a compelling additional economic argument for the thesis's core thesis.

Scale sensitivity analysis. Apply the NPV framework to operations at 1,000, 5,000, 20,000, and 50,000 sow scales to identify how the per-sow incremental NPV changes with operation size. Very large operations may experience diminishing returns to boar-selection intensification, while very small operations may have higher per-sow fixed costs that dilute the benefit. Such scale-specific results would inform producer-specific adoption guidance.

PRRS-resistant genetics scarcity-driven adoption pathway. The commercial deployment timeline of gene-edited PRRS-resistant pigs (Brian T Burger 2024) creates a forward-looking research agenda that builds directly on the framework developed in this thesis. Once the founding population of PRRS-resistant boars enters commercial channels, the supply will be severely constrained relative to U.S. commercial demand. Genetic suppliers will be unable to meet that demand through CAI-equivalent dose concentrations, because the available cell volume from the small founder population would be exhausted serving a fraction of the addressable sow inventory. The market response will therefore be a near-mandatory shift to reduced-dose PCAI and DIUI to extend the reach of each elite boar across more females. This scarcity-driven adoption pathway is the inverse of the value-driven pathway analyzed in this thesis: in the scarcity case, producers will adopt PCAI not because the standard NPV math justifies it, but because access to the desired genetics is contingent on adoption. Future research should quantify the implied PCAI and DIUI adoption acceleration under various PRRS-resistant supply curves and value-capture scenarios, including the question of how much of the disease-resilience economic benefit accrues to the producer versus to the genetic supplier under different licensing structures.

4.10 Pathways to Increased Adoption in North America

4.10.1 PCAI Adoption Acceleration in North America

The economic case established in this thesis indicates that the North American pork industry holds a substantial untapped opportunity in fuller PCAI adoption, both extending the technique to producers who have not yet adopted it and converting the producers currently in half-adoption to full adoption with appropriate dose specification. With current PCAI penetration in the United States at approximately 40% (R. Knox 2025), and with much of that 40% operating as half-adoption rather than as full PCAI with reduced sperm concentration, the path to industry-wide value capture begins not with new technology development but with structured implementation support for the technology that already exists. Three implementation levers, addressed in turn below, are the most direct routes to acceleration.

The first lever is structured training and technical support at the sow farm level. PCAI is not a complex technology, but it is a different protocol from CAI: the catheter geometry differs, the deposition target differs as well as passing through the cervix. Producers who have used CAI for decades report that the transition feels straightforward in concept but requires several weeks of supervised practice before insemination crews achieve consistent results. The most effective adoption pattern observed in commercial deployments combines a structured implementation guide with on-farm crew training delivered by either the GTC supplier or a third-party technical service team, followed by a defined performance-monitoring period during which farrowing rates and total born are tracked against the pre-transition baseline to confirm equivalence. PCAI implementation should therefore be accompanied by explicit guide-and-crew training rather than treated as a self-directed protocol substitution: technique adoption without training risks compromised reproductive performance during the learning curve, which then becomes the basis for the producer's permanent rejection of the technique even though the technology itself works as advertised.

The second lever is producer education on the economics of dose concentration. A central finding of this thesis is that the economic case for PCAI is not built on labor savings at the sow farm, those savings are real but small relative to the total operation but on the unlocking of more aggressive boar selection at the GTC, which compounds downstream into improved offspring performance. This connection is not intuitive. A producer reasoning informally about PCAI naturally focuses on the things they can see directly: the catheter premium they pay, the time saved during insemination, and the same farrowing rate they observed before the transition. The economic value sits one step removed from this view in the smaller boar inventory the GTC can now maintain, the higher genetic index of the boars that remain, and the resulting downstream improvement in litter performance, growth efficiency, and carcass value. Industry education that walks producers through this chain explicitly ideally with operation-specific NPV calculations rather than generic case studies is a necessary complement to the technical training described above. The producer needs to understand why lower concentration is economically better, not merely accept that it is.

The third lever is expanded availability of independent commercial validation data. Producers considering technology change reasonably want to see results from operations comparable to their own before committing capital and protocol change. The peer-reviewed literature established the biological feasibility of PCAI at reduced concentrations more than fifteen years ago (A. Mezalira, D. Dallanora and M. Bernardi, et al. 2005), and the international experience demonstrates large-scale commercial viability. What is less abundantly available in North America is the validated multi-farm dataset showing realized differential performance between matched cohorts operations that transitioned to full PCAI compared against operations that remained on CAI, with comparable sow genetics and management. Industry organizations including the National Pork Board, university extension programs, and individual GTC suppliers have an opportunity to commission and publish this validation data, which would directly address the residual uncertainty that holds back conservative producers. Better data on concentration levels and reproductive results enables producers to change protocols feeling confident in the outcomes confidence that case studies and biological mechanism arguments alone do not provide.

4.10.2 Outlook for DIUI: Multiplier-First, Then Selective Commercial Deployment

DIUI occupies a different position in the adoption curve than PCAI. Where PCAI is a mature, validated technology underused at the commercial level, DIUI is a mature technology used in narrow applications, primarily in research trials, multiplication and contingency response that has not yet established a routine commercial role. The forward path for DIUI is therefore not a simple acceleration of an existing trend but a phased expansion through specific deployment contexts. The recommended sequencing is multiplier-first, then progressive expansion into commercial settings, with DIUI accompanying rather than replacing other reproductive technologies.

At the multiplier level, DIUI's efficiency in disseminating elite genetics from a small founder population is its highest-value application. A pure-line multiplier farm propagating an elite boar line across nucleus and grandparent populations benefits from DIUI's 1:3,000 ratio, or higher, because the genetic value per dose is high and the population being inseminated is itself genetically elite. This is the segment where DIUI has been used for years; the recommendation is for systematic expansion of DIUI capacity within existing multiplier operations and accompanying technical training programs to ensure operator proficiency. From the multiplier base, expansion into the upper tier of commercial sow farms, operations with high baseline performance, strong herd health status, and management capacity to absorb a more demanding insemination protocol represents the next deployment phase. Lower-tier commercial operations should not be the early adoption target for DIUI; the technique's narrower margin for operator error and higher demands on stud-level single-sire identification make it less suitable for operations without strong management infrastructure.

DIUI's commercial role is best understood as one component of a broader reproductive technology platform rather than as a standalone adoption decision. Frozen semen, embryo transfer, in-vitro fertilization, and DIUI all operate on the same underlying principle of expanding the genetic reach of elite animals beyond what natural reproductive cycles permit. In multiplier operations and high-tier commercial operations, these technologies are increasingly deployed in combination with frozen semen for international genetic distribution, DIUI for low-cell-count dissemination of elite boars within the herd, and embryo transfer for accelerated dam-line propagation. Industry development of DIUI should be coordinated with development of these complementary technologies and with operator training advancing in parallel.

A practical context in which DIUI use has expanded substantially is contingency response to dose-supply disruption. When a stud experiences a disease event that takes down production and needs to rely in other boar studs, or closing borders to enter live boars into a country, the rational response is to reduce the cells per dose, moving toward PCAI specifications and, in extreme cases, toward DIUI specifications to stretch available semen across the demand. This contingency response is not new; it has been used reactively for years. What it demonstrates is that the biological feasibility of low-cell-count protocols is well-established within the industry's operational repertoire, even where they are not used routinely. The same operational knowledge that supports contingency response can be redeployed proactively to support routine adoption.

4.10.3 PRRS-Resistant CRISPR Genetics: A Potential Forcing Function

The most consequential potential expansion of DIUI in the medium term is its possible role as the dissemination technology for PRRS-resistant CRISPR-edited genetics. The commercial introduction of PRRS-resistant lines, which is approaching regulatory approval as of this writing (Brian T Burger 2024), will create an industry-wide need to disseminate a small founder population of edited animals across the broad commercial sow herd as rapidly as possible. The economic motivation is direct: PRRS imposes substantial annual losses on the U.S. industry through reproductive failure, mortality, biosecurity expenditure, and lost throughput; the value of resistance, once available, would justify aggressive deployment effort.

The mathematical reality of disseminating CRISPR-edited resistance is that the founder boar population is small by design. CRISPR-edited animals are produced through a controlled process that does not scale arbitrarily, and regulatory approval pathways will likely impose additional constraints on the founder generation. To reach a meaningful share of the U.S. commercial herd within a reasonable time horizon, the industry would need to use the lowest-cell-count dissemination protocols available, PCAI at reduced concentrations and, where the biology allows, DIUI. The boar:sow ratio mathematics from Section 3.4.2 make this concrete: a single elite resistant boar at PCAI 1.5×10^9 cells could supply approximately 495 sows per year, while at DIUI 0.05×10^9 cells the same boar could in principle supply more than 14,000 sows. In a regime where founder-population scarcity is the binding constraint, the higher boar:sow ratios become not a matter of operational efficiency but of feasibility.

It does not follow that DIUI becomes mandatory upon CRISPR commercialization. The industry has alternatives, including PCAI at reduced concentration (already validated commercially) and gradual expansion of the founder population through conventional breeding. The honest formulation is that DIUI represents a potentially valuable tool to keep an eye on as the CRISPR pathway matures. If founder-population constraints prove tighter than current expectations, or if the rate of resistance dissemination required by industry conditions exceeds what PCAI can deliver, DIUI provides a tested fallback. The recommended posture for the industry is therefore to maintain operational readiness for DIUI through continued multiplier-level deployment and infrastructure development, without committing prematurely to commercial DIUI as the default protocol. This positions the industry to scale DIUI quickly if the CRISPR opportunity demands it while retaining flexibility if PCAI alone proves sufficient.

4.10.4 Summary of Adoption Recommendations

Increased PCAI adoption in North America requires structured implementation training, producer education on the economic logic of reduced concentration dosing, and expanded commercial validation data. These are not technology problems but adoption-infrastructure problems, and they are addressable by industry organizations, GTC suppliers, and university extension programs working in coordination. The forward path for DIUI is multiplier-first commercial expansion, paired with broader reproductive technology platforms including frozen semen and embryo transfer, with the PRRS-resistant CRISPR pathway representing a potential medium-term forcing function that could materially accelerate DIUI deployment if and when commercialization requires the most aggressive available dissemination protocols. The economic findings of this thesis are technology-readiness rather than technology-adoption findings: the value is real and large; the question is whether the industry organizes itself to capture it.

4.11 Closing Statement

This thesis has used Net Present Value analysis to evaluate the economic case for adoption of Post-Cervical and Deep Intra-Uterine Artificial Insemination in U.S. commercial swine production. The headline finding, that PCAI is economically justified over CAI only when implemented together with a boar genetic selection upgrade, is robust across the full sensitivity range tested. Producers who adopt PCAI as a labor-saving technology without concurrent genetic upgrade will capture only a fraction of the available economic value, and under the risk-adjusted framework applied here, will destroy value relative to continuing with traditional CAI.

The central management implication is therefore not a question of technique selection in isolation, but of technique-and-genetics bundling. The post-cervical catheter is not economically interesting for its own sake; it is interesting because it enables genetic dissemination from fewer, higher-index boars, and the dissemination benefit is where the majority of the NPV resides. Producers, integrators, and genetic suppliers who recognize this coupling will capture the available value; those who treat PCAI as an incremental protocol change will not.

An additional finding that emerged from the confirmed 2025 U.S. commercial input set is worth emphasizing. The operational economics of PCAI adoption are actually favorable on a stand-alone basis (smaller catheter cost premium and meaningful labor savings), which means a producer using a simple payback test will be tempted to adopt PCAI without the genetic upgrade. The risk-adjusted NPV framework reveals why this temptation should be resisted: the combined effect of the 100-basis-point discount rate differential and the absence of downstream genetic value capture turns an apparently profitable protocol change into a value-destroying decision. The case for PCAI plus genetic adoption does not rest on any single favorable input assumption; it rests on the structural relationship between AI technique, boar selection intensity, and the four-stage value chain in U.S. pork production. The thesis’s central argument, that the value proposition of PCAI is inseparable from the value proposition of genetic upgrade, is confirmed by the analysis and is expected to remain robust as input values evolve with market conditions.

The supplemental NPV Excel model is designed to be updatable as U.S. market conditions evolve, and the Assumptions tab is structured to allow producers and consultants to re-run the analysis for their specific operation scale, cost structure, and risk tolerance. The model produces scenario-by-scenario NPV, IRR, Profitability Index, and incremental-versus-baseline results suitable for presentation to producer boards, GTC investment committees, and academic audiences. Together with this written analysis, the model is intended to serve as a practical tool for the U.S. swine industry as it considers the next phase of reproductive technology adoption — a phase in which the economic case for PCAI plus higher-index genetics is strong, well-quantified, and increasingly time-sensitive given the approaching commercial availability of PRRS-resistant genetics.

A practical note for industry leaders is that the largest near-term value-capture opportunity is not net-new adoption among non-PCAI producers, but completion of half-adoption among the substantial population of producers currently using PCAI catheters with CAI-equivalent dose concentrations. These producers have already crossed the protocol implementation barrier at the sow farm; they need only reduce dose concentration at the GTC to capture the difference between Scenario B and Scenario C, equivalent to approximately $6.4 million of incremental NPV per 5,000 sows over five years. Industry consolidation toward larger GTCs with stronger genetic index management discipline and superior processing infrastructure will accelerate this completion, and looking further ahead, the commercial availability of PRRS-resistant genetics will turn the partial-adoption configuration from an economic inefficiency into an outright barrier to participating in the next generation of swine genetics. The window for retaining a CAI-equivalent dose specification under a PCAI catheter protocol is closing, and the producers, integrators, and

GTCs that recognize this convergence will be positioned to capture both the present economic value and the future generations of genetic technology.

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