

ANDRE ROZEMBERG PEIXOTO SIMÕES

**THE DYNAMIC IMPACTS OF FARM-LEVEL TECHNOLOGY
ADOPTION ON PRODUCTION, PRICES AND PROFITABILITY
IN BRAZIL'S DAIRY SUPPLY CHAIN**

Teses apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Economia Aplicada, para obtenção do título de *Doctor Scientiae*.

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Kennya Beatriz Siqueira



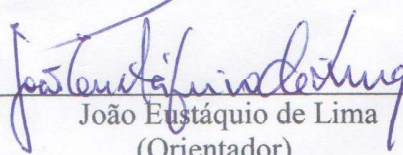
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BIOGRAPHY

Andre was born in 1978 in the city of Rio de Janeiro. He spent much of his childhood and youth in a country town where he was heavily influenced by his experiences with the rural way of life. When he was 19 years old, entered to the Universidade Federal de Viçosa where started to build his professional career. Graduated in May of 2002 in animal science, he immediately entered the Masters program in Applied Economics, obtaining that degree in October of 2003. Since his undergraduate studies, he has been dedicated to studying milk production systems and how to help farmers and improve their lives. In 2004 was designated as professor at the Mato Grosso do Sul State University to work in the animal science course in the city of Aquidauana. Since then he has developed many research and extension projects focused on the dairy supply chain including the *Programa Rio de Leite*, for which he was one of the founders and has received several public recognitions. After 10 years working as a professor, he was approved in 2014 as a Ph.D. student in Applied Economics and went back to Viçosa to complete his academic training. During this period Andre had the opportunity to spend 10 months in the U.S. as a visiting researcher at Cornell University improving his knowledge in computational simulation models involving socio and bio-economic aspects. He submitted his Ph.D. thesis in September 6th, 2018.

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ABSTRACT

SIMÕES, Andre Rozemberg Peixoto, D.Sc. Universidade Federal de Viçosa, September, 2018. **The Dynamic Impacts of Farm-level Technology Adoption on Production, Prices and Profitability in Brazil's Dairy Supply Chain.** Advisor: João Eustáquio de Lima. Co-advisors: Roberto Max Protil, Altair Dias Moura and Adriano Provesano Gomes.

Technology adoption in agriculture is often viewed as a way to increase production, farm income and agricultural competitiveness. However, additional production due to aggregated technology adoption generally lowers prices, which can reduce or completely offset benefits for farmers. We developed an empirical System Dynamics (SD) model to assess the market dynamic and distributional impacts of three rates of exogenous feed and genetics technology adoption by five dairy farm sizes in Brazil from 2006 to 2016. The SD model represented key stock-flow-feedback structures in Brazil's dairy supply chain, integrating dairy farm technology adoption with dairy processing and consumer demand. Consistent with previous literature, technology adoption lowers milk and dairy product prices, although adopting farms generally saw increases in Net Farm Operating Income (NFOI) and reductions in income variation. Non-adopting farms generally had lower average NFOI and more frequent negative NFOI, regardless of farm size. The overall shares of Brazilian milk production and farm incomes by farm size were markedly different for different adoption assumptions, indicating the potential of technology adoption to cause structural change. Technology adoption also provided considerable benefits to post-farm supply chain participants and consumers through lower raw material and product prices. Dynamic complexity effects resulted from technology adoption: large differences in average farm milk prices between adoption and Baseline scenarios early in the adoption process became smaller after an adjustment period. Technology adoption *per se* was not sufficient to mitigate observed negative NFOI values during 2014 to 2016. The dynamic simulation model provides useful insights to industry stakeholders and government policy makers about the potential effects of alternative sector development strategies and technology promotion programs. Future work to develop more consistent dairy sector supply and utilization data and describe farm-level technology adoption processes would complement our dynamic assessment of dairy technology adoption impacts in Brazil.

RESUMO

SIMÕES, Andre Rozemberg Peixoto, D.Sc. Universidade Federal de Viçosa, setembro de 2018. **O Impacto Dinâmico da Adoção de Tecnologias nas Fazendas Leiteiras do Brasil sobre a produção, preços e lucratividade da cadeia produtiva.** Orientador: João Eustáquio de Lima. Coorientadores: Roberto Max Protil, Altair Dias Moura e Adriano Provesano Gomes.

A adoção de tecnologias na agropecuária é frequentemente vista como uma forma de aumentar a produção, a receita das fazendas e a competitividade setorial. Entretanto, a produção adicional, geralmente, leva à redução de preços o que pode eliminar os potenciais benefícios para produtores rurais. Neste sentido, foi desenvolvido um modelo de Dinâmica de Sistemas (DS) para avaliar a dinâmica do mercado e os impactos distributivos de três taxas exógenas de adoção de tecnologias, relacionadas ao sistema de alimentação e melhoramento genético, em cinco categorias de tamanhos de fazendas no Brasil entre 2006 e 2016. O modelo de DS representou as principais estruturas de estoque e fluxo da cadeia produtiva, integrando a produção primária com o setor de processamento e a demanda dos consumidores. De acordo com estudos anteriores, encontrou-se que a adoção de tecnologias causa redução nos preços do leite e dos derivados lácteos, contudo, fazendas que adotam tecnologia experimentam aumentos e menor variação na Margem Líquida (ML). Não adotantes, geralmente, têm menor ML e maior frequência de resultados negativos independente da escala de produção. A proporção de distribuição da produção de leite e das receitas é marcadamente diferente para diferentes tamanhos de fazendas indicando o potencial que a adoção de tecnologia tem sobre as mudanças estruturais. Além disso, a adoção resulta em consideráveis benefícios nos segmentos a jusante do setor produtivo e consumidores, por meio de menor custo de matéria prima e preços dos derivados. Foram observados efeitos dinamicamente complexos ao simular a inovação tecnológica, por exemplo: a diferença entre o preço do leite observado e o preço simulado nos cenários foi maior no início do processo de adoção e tornou-se menor depois de um período de ajuste. A adoção de tecnologia *per se* não foi suficiente para mitigar valores negativos de ML no período entre 2014 e 2016. O modelo gerou *insights* úteis para formuladores de políticas públicas sobre os efeitos de desenvolvimento de estratégias alternativas e programas de difusão de tecnologias. Trabalhos futuros, baseados em dados mais consistentes sobre a oferta e consumo de derivados lácteos e na descrição do processo de adoção tecnológica, poderiam complementar a avaliação dinâmica sobre os impactos sobre toda a cadeia produtiva no Brasil.

1. INTRODUCTION

Studies about diffusion of innovation in agriculture and in dairy have a long history. The main motivation for many research projects in this topical area is that new technology can offer an opportunity to increase production and farm income (Feder et al., 1985; Verner and Gubbels, 1967). Technology adoption is also viewed as the mechanism to maintain the income of family farms while also supporting agricultural competitiveness. However, there is evidence that the aggregated average rates of productivity growth observed in Brazilian agriculture (and probably in other developing countries) conceals relevant diversity, including the exceptional performance by some farms and very poor performance by others (Rada et al., 2018). In this sense, structural heterogeneity at the farm level must be considered when assessing the likely of adoption of new technologies by individuals and the impact of diffusion on markets (Howley et al., 2012).

Many studies of technologies in agriculture and in dairy more specifically attempt to explain the patterns of adoption behavior based on farmers attributes (e.g. age, education, years farming, size, income) social interaction (e.g. network and communication), and the perceived benefits of the technology (Asres et al., 2012; Baumgart-Getz et al., 2012). Other scholars have invested significant time and effort analyzing the role of various constraints in the adoption process (Feder and Umali, 1993), some suggesting an “innovation systems” approach (Spielman, 2005). In contrast, relatively few studies are focused on the effect of technology adoption on aggregated market variables such as supply-demand balance, prices, farm profitability and changes in farm structure. Zepeda et al. (1991) estimated the aggregated impact of bovine somatotropin (bST) adoption on U.S. farm milk prices and dairy product prices. They assessed four bST adoption scenarios using an econometric model, and found that the California milk supply would increase over the baseline forecasts if bST were adopted and farm milk prices, retail product prices, and fluid milk prices would decrease. Weersink and Tauer (1990) simulated the regional and temporal impacts of technical change in the U.S. dairy industry in terms of production and income distribution through a dynamic equilibrium model. Their main findings were that higher milk production would lower prices and have negative impacts on profitability and cow numbers. Thus, extant studies of the market impacts of technology adoption in dairy tend to suggest that the benefits of technology adoption may not accrue entirely (or, to any great extent) to farmers, and there may be counterintuitive negative effects on the farm sector or farm structure (Johnson and Ruttan, 1997; Parsons and Nicholson, 2017). As with other studies of

technology adoption at the market level, consumers and other supply chain actors also benefit from technology adoption at the farm level. This is somewhat contrary to the perception of at least some applied agricultural scientists that technological development primarily benefits farmers and that increased production should be an implicit or explicit goal.

Although previous studies have examined various aspects of technology adoption by Brazilian dairy farms (Brockington et al., 1992; Campos et al., 2014; Moraes et al., 2015; Novo et al., 2013) no study assess the dynamic impacts of scaled-up technology adoption on aggregated market outcomes and farm-level profitability by farm-size categories. Additional knowledge of these impacts is relevant for industry decision makers from input suppliers to food retailers, and for government policy (e.g., subsidy) choices. Although government agencies and private companies (including dairy processors) spend considerable resources on technology development and diffusion, usually hoping that it will improve farm-level productivity and profitability, they might not appreciate the aggregated impacts if those technologies are widely adopted. These impacts can include basic and short-term outcomes such as those on prices and sales, but also longer-term and structural change dynamics with substantive implications for income distribution. These longer-term outcomes can be counterintuitive and thus difficult to anticipate without a formal dynamic analysis. Assessing the impacts of technology adoption is relevant for the Brazilian dairy industry due to the importance of this sector in the national economy and because of the gap between observed and potential productivity at the farm level that constrains the industry's global competitiveness.

To illustrate the importance of the dairy industry in Brazil, it was the fourth-largest cow's milk producer in the world, with annual production of 33 billion liters in 2016, behind only the United States (96 billion), India (77 billion) and China (37 billion) (FAO, 2018). Brazilian milk production occurs on 1,171 million farms (23% of all farms in the country) that are widely dispersed throughout the country, reflecting a diverse set of social, cultural, and climatic factors (IBGE, 2017). As a result, dairy farms are heterogeneous in terms of technology adoption intensity and production scale (Silva et al., 2016; Simões et al., 2017; Telles et al., 2017). According to Gomes (2006) "technological duality" is a prominent feature in the Brazilian milk production because farmers using higher-productivity technology operate side by side with farmers using low-input, low-output systems with limited adoption of newer available technologies. From 2006 to 2016, cow productivity in Brazil increased from 1,250 to 1,709 liters/cow/year indicating that some farmers are adopting technology and improving their

production systems over time. However, despite this progress, liters per cow per year is still low when compared to the United States (10,328), New Zealand (4,249), and European Union countries (6.590) (FAO, 2018). Although these higher levels of productivity may not be appropriate for the majority of Brazil's dairy farms, they illustrate the potential to increase productivity that can be evaluated for its relevance in the Brazilian context.

Cross-sectional studies of implemented technologies on Brazilian dairy farms have indicated that increased production and economic efficiency gains are possible for individual farms. Novo et al. (2013) used Data Envelopment Analysis to show that, on average, family farmers who joined the “*Programa Balde Cheio*” (Full Bucket Programme) increased milk production three-fold and their gross margin doubled due to lower costs and growth in cow numbers. In contrast, at a regional level during 2003 to 2009, there was a reduction in overall milk production of 8%, which is due to competition for land, mainly for sugarcane production and the increased opportunity cost of labor in urban areas. Participation in the FBP made dairy farming competitive in financial terms compared with soybean and sugarcane production.

However, if technology is broadly adopted over time the additional supply resulting from increased productivity has the potential to lower prices *ceteris paribus*, and this could more than offset the benefits of technology adoption. Further, the negative effect via lower prices is not equally distributed to all types and farm-size categories. Previous research (e.g., Parsons and Nicholson, 2017) on the dynamics of livestock technology adoption has suggested that adopters and larger farms would experience improved profitability whereas smaller non-adopting farms would probably exit in the long run. This agrees with the findings of Quiroga and Bravo-Ureta (1992) who noted that lower prices due to technology adoption tend to lead to larger and fewer dairy farms. These potential negative effects leave unanswered questions about what rates of technology adoption (and by which farms) would be sufficient to cause pernicious effects that would offset the potential benefits. A further important question is the extent to which technology adoption by one category of farms affects the economic performance of other farms. Finally, the dynamics of the market effects is a relevant consideration. Previous works have indicated that milk supply elasticities will differ over-time (Bhattacharya et al., 2016; Bozic et al., 2014; Chavas and Klemme, 1986) and that supply and demand respond to market stimuli with delays. Thus, it would not be surprising to observe dynamically complex outcomes (patterns of behavior that differ in the short and long run) in response to the adoption of productivity-enhancing

technologies by Brazilian dairy farms. These relevant questions can be addressed with the simulation modeling approach developed for this study, providing relevant insights about the relationship between technology use and the behavior of milk prices in Brazil as suggested by Olaya (2015).

Thus, the main objective of this study is to assess the market dynamics and the distributional impacts of alternative assumptions about exogenous technology adoption by Brazilian dairy farms. The particular interest is the distributional impact on farm incomes and on the proportion of milk production for different farm size classes. To achieve this overall objective, the following are the relevant sub-objectives:

- a) develop and evaluate a dynamic causal model that links farm-level technology adoption decisions with market outcomes such as milk production, cow numbers, milk prices, product prices and product quantity demanded; and
- b) specify and analyze a set of relevant technology adoption scenarios with three different adoption rates and extent of adoption by smaller or larger farms;

The dynamic model developed to address these objectives is an adaptation to the Brazilian context of the previous work of Nicholson and Stephenson (2014), who described the potential impacts of implementation of a margin protection program in the U.S. dairy industry using a conceptual analysis (feedback loop diagram) and an empirical System Dynamics model. Both that model and our were adapted from the commodity supply chain model described in Sterman (2000) and the initial formulation dating back to Meadows (1970).

Beyond this introduction and the following *Dynamic Hypothesis* description, the work is organized as follows: *Methods and Data Description* including a detailed discussion of the model structure (stock-and-flow diagrams), the model assessment and validation, and the data sources. The *Results* section summarizes the key findings divided into three subsections with differing levels of farm size and temporal aggregation. The *Discussion* compares our findings with those from previous research including, novel contributions to knowledge. Finally, the *Conclusion* highlights the main findings in brief and the *Limitations and Future Research directions*. The *Appendix* sections provide additional detail relevant for model replication and additional detailed simulation results.

2. THE CAUSAL LOOP DIAGRAMS OF DAIRY MARKETS UNDER TECHNOLOGY ADOPTION AND THE DYNAMIC HYPOTHESIS

The System Dynamics (SD) method is an appropriate approach to assess dynamic problems (behaviors over time that are considered problematic by decision makers) in the presence of significant response delays involving multidimensional variables connected by feedback processes. SD is a method to specify causal (endogenous) models that capture dynamics arising from underlying system structure. The SD method often commences using two basic system diagramming tools, Causal Loop Diagrams (CLD) that provide a visual depiction of system feedback structure and the Stock-and-Flow diagram that highlights delay structures and rates controlling key dynamic outcomes. Together, these diagrams describe what is termed the “dynamic hypothesis”, that is, a depiction of the hypothesized system structure that causes an observed problematic behavior. These diagramming tools provide a basis for the development and evaluation of a formal mathematical simulation model (in SD, a system of differential equations solved by numerical integration; Sterman, 2000). In our case, the CLD provides a mechanism to depict the structures that can lower or offset the net benefits of technology adoption, and the potential for dynamically complex behaviors.

The CLD is an important tool for diagrammatic representation of the feedback structure of systems and is useful for representing in a qualitative and simplified way hypotheses about causes of dynamics. A CLD consists of key system variables connected by arrows denoting the causal influences among the variables and identifying the important feedback loops. Variables are connected by causal links that can assume either positive (+) or negative (-) polarity. A positive polarity link means that a change in one variable results in change in the same direction for another variable, other things being equal. A negative polarity link indicates that a change in one variable results in a change in the opposite direction for another variable, again, other factors being equal. Parallel bars shown in the link arrow represent the most important delays in the system. Variables that do not have arrows pointing to them (e.g., milk production costs, exports) are assumed exogenous (i.e., determined outside the model boundary) for the purposes of the analysis. The loops in a CLD are highlighted by a loop identifier which indicates loop polarity, that is, whether the loop creates positive (reinforcing - R) or negative (balancing - B) feedback. The way to determine the loop polarity is to trace the effect of a change in one of the variables as it propagates around the loop. If the feedback effect reinforces the

original change, it is a reinforcing or positive loop. If it opposes the original change, it is a negative or balancing loop.

Our CLD indicates that there are two key reinforcing (R1 and R2) and two key balancing loops (B1 and B2) in the Brazilian dairy sector, each of them with important delays (Figure 1). The variables *Cow Numbers* and *Dairy Product Inventories* are inside a box to represent the main stocks of the model. Variables outside the loops represent exogenous inputs.

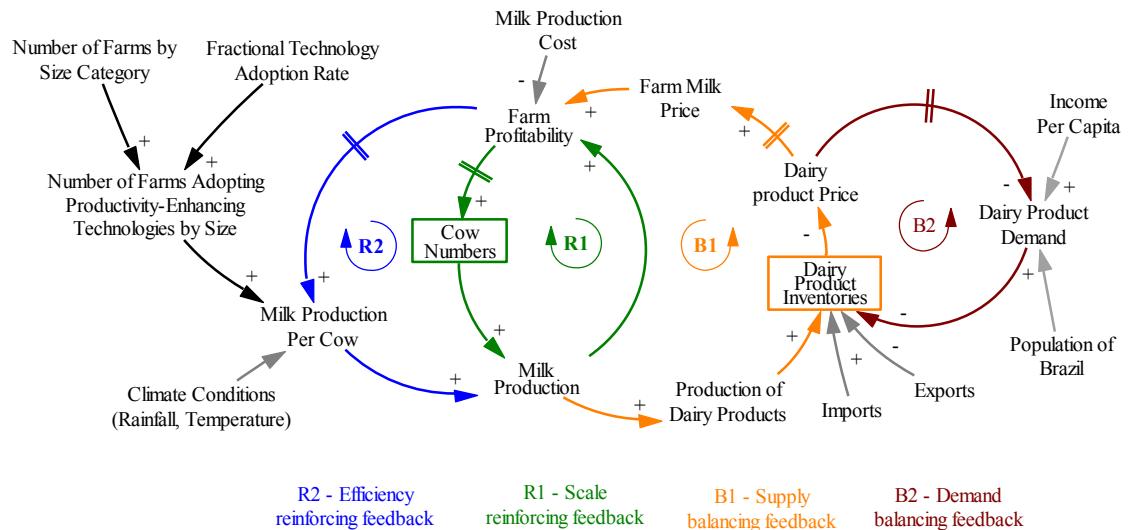


Figure 1 - Causal Loop Diagram representing the conceptual model and the main feedback loops with the endogenous and exogenous variables.

This CLD can be used to undertake a qualitative assessment of potential impacts of technology adoption – although formal simulation modeling is still necessary to generate relevant insights. Although technology adoption is endogenous (depending on a variety of factors, as noted above) the diagram assumes that the adoption process is exogenous (as in the simulation model to be described subsequently) to show the relevant feedback effects more clearly. The rate of technology adoption (*Fractional Technology Adoption Rate*) is assumed to vary by farm size (and scenario) and determines a key exogenous input, the *Number of Farms Adopting Productivity-Enhancing Technologies*. The primary effect of adoption of technology is increasing *Milk Production Per Cow* and consequently overall *Milk Production*. Many analyses of technology adoption would consider short-run effects only to the point of increased milk production, without consideration of further relevant follow-on feedback effects. However, higher *Milk Production* would increase *Farm Profitability* and, with a delay due to both biological and economic factors, result in an increase in *Cow Numbers* that also increases *Milk Production*. This component of the

system is thus a reinforcing feedback loop R1. Increased *Farm Profitability* also reinforces with a delay the initial effect of technology adoption on *Milk Production Per Cow*, through feedback loop R2. Thus, the initial effect of technology adoption on milk production is enhanced by two reinforcing feedback loops.

However, in addition to the reinforcing processes of exogenous technology adoption there are balancing effects that occur through changes to the relative supply and demand balance for milk and dairy products. Increased milk production will result in increased *Production of Dairy Products* and increased *Dairy Product Inventories*. Increased *Dairy Product Inventories* has a decreasing effect on *Dairy Product Price* and *Farm Milk Price* with a delay. A lower *Farm Milk Price* has a negative effect on *Farm Profitability* that then also affects both *Cow Numbers* and *Milk Per Cow*. These balancing effects have the potential to partially or completely offset the positive effects of the technology adoption on production and farm-level profitability, through loop B1. However, the effect of balancing loop B2 can help to offset the potential negative effects. Lower *Dairy Product Price* will positively affect *Dairy Product Demand*, which will lower *Dairy Product Inventories* and have a positive influence on *Dairy Product Price* (and therefore, *Farm Milk Price* and *Farm Profitability*). Therefore, the net effects on *Farm Profitability* and the production outcomes overall and for each farm category will depend on which feedback loops dominate, the two reinforcing loops that enhance milk production or the balancing loops that lower farm milk prices. Note that without a formal simulation model representing these processes empirically, it is not possible to determine the direction or magnitude of changes in the outcomes with technology adoption.

Other exogenous factors are shown that affect both the supply and demand components in this conceptual model. Increases in *Milk Production Costs* would reduce *Farm Profitability* (and thus *Milk Production*) and the *Climate Conditions* can affect the *Milk Production* (primarily through impacts on *Milk Per Cow*) which will vary by season. *Imports* and *Exports* influence *Dairy Product Inventories* and demand for dairy products is influenced by *Population* and *Income Per Capita*. Although exogenous effects are relevant, a key consideration in SD models is that the observed patterns of dynamic behavior for variables will depend primarily on the dominant endogenous feedback loop processes defined in the model structure, which also can vary over time.

3. METHODS AND DATA DESCRIPTION

We developed a System Dynamics model based on the generic commodity market model proposed by Sterman (2000, Chapter 20) that is a generalization of the seminal model of hog cycles published by Meadows in 1970. This model defines feedback loops between supply and demand with relevant time delays that generate the observed oscillations in farm milk prices endogenously. Further, the feedback loops include many components from the U.S. dairy industry model developed by Nicholson and Stephenson (2014, 2010), with modifications in the relevant parameters and in some structures to represent more appropriately the production sector dairy product manufacturing, and product demand of the Brazilian dairy industry. We also included major adaptations in milk price formation, government market regulation and programs for margin protection observed in U.S. but not in Brazil. Thus, the model comprises three interconnected modules: 1) Farm Milk Supply with a herd aging chain and farm-level profitability, 2) Dairy Processing and Demand, including exports and imports of the most important products, and 3) the Milk Price Formation determining dairy product and farm prices. A detailed description of all equations and parameters are included in Appendix A whereas in this section, only the main components of the model are presented.

We choose 2005 as a base (initial) year because it corresponds to the year of publication of the latest Brazilian Agricultural Census and the Dairy Livestock Survey of Minas Gerais by Gomes (2006). The data used for model development also include official sources such as IPEA, IEA, CEPEA, MDIC and EMBRAPA¹ and others such as specialized literature and specialist opinion. We interviewed fifteen specialists from different segments of the Brazilian and the U.S. dairy industry and academic institutions (Appendix B, Table B1) to estimate some parameters and to assess the behavior over time of some variables. Many parameters (especially from the herd aging chain) were estimated based on Minas Gerais State as a proxy for the whole country when national data were not available. . This assumption is reasonable because dairy production systems in Minas Gerais encompass a broad range of milk production systems (Simoes et al., 2015; Zoccal et al., 2007), the state is the largest milk producer (25%), and has a strong commercial linkage with other states (Carvalho et al., 2014; Fernandes et al., 2010;

¹ IBGE - Brazilian Institute of Geography and Statistics; IPEA - Institute of Applied Economic Research; IEA – Institute of Agricultural Economics; CEPEA - Center for Advanced Studies on Applied Economics; MDIC – Ministry of Industry, Foreign Trade and Services; EMBRAPA - Brazilian Agricultural Research Corporation

Siqueira et al., 2010). Seasonality and other local variables can also vary among the Brazilian regions however, we will demonstrate that the model can be useful to interpret the national dairy market at the aggregate level. The System Dynamics modeling approach facilitates incorporation of data from a broad range of sources, including numerical, written and mental data. Thus, our data utilization is consistent with its best practice. The model was built using the software Vensim version DSS® that is a specific tool for system dynamics modeling.

3.1. Farm Milk Supply

The use of stratified analysis of dairy farming is typical in dairy industry studies. Thus, in accordance with the most relevant surveys cited by Figueiredo and Gomes (2009) about Brazilian dairy farming we choose to use five farm-size categories stratified by the daily milk production per farm (Table 1). Further, the data provided by Gomes (2006) allowed simulation of the milk production systems based not only on current technology level but also their responsiveness to market stimuli.

Table 1 - Categories of dairy farms based on production scale and proportion of milk production and cows in milk.

| Farm-size categories (Liters/day) | Proportion of farms (%) | Proportion of Milk Production (%) | Cows in milk per farm (head) | Proportion of Cows* |
|-----------------------------------|-------------------------|-----------------------------------|------------------------------|---------------------|
| Up to 50 | 44.0 | 8.2 | 8.0 | 15.5 |
| 51 – 200 | 35.4 | 23.4 | 19.6 | 30.5 |
| 201 – 500 | 14.0 | 23.9 | 38.6 | 23.7 |
| 501 – 1,000 | 4.0 | 15.1 | 66.6 | 11.7 |
| Over 1,000 | 2.6 | 29.4 | 162.9 | 18.6 |

*Calculated:

$$\left(\text{Cows in milk per farm}_i \times \text{Proportion of farms}_i \right) / \sum_{i=50}^{1000} \left(\text{Cows in milk per farm}_i \times \text{Proportion of farms}_i \right)$$

Source: Dairy Livestock Survey of Minas Gerais, Gomes (2006)

The *Actual Milk Per Cow* is based on the expressed genetic potential, feeding strategies, and is also influenced by an exogenous seasonal component (Figure 2). The maximum genetic potential growth rate is a trend component of the milk production per cow and was calibrated to increase over time at 2% per year, consistent with the observed data and suggested by previous work (Chavas and Kraus, 1990). In addition, the ratio of farm milk price to the feed cost per liter influences endogenously the production practices (mainly feed strategy) and consequently milk production per cow in the short-term. The amplitude of the seasonal component is exogenously estimated for each category and calibrated to match the aggregated milk production and the average national price. According to the IBGE database, the formal fraction of milk production in Brazil

parameters that determine the technological level of each system. The net birth rate controls the inflow into calves' stocks and takes into account the number of calves born based on the calving interval, the fraction of female calves born (adoption of sexed semen can modify this parameter) and mortality rate. The weaning rate uses the parameter time to wean to control the flow from calves to heifers' stock. The maturation time determines the outflow rate from the heifer's stock (first calving rate). The model uses a high-order delay instead of a first-order delay from heifer to cow transition. A first-order delay has the following mathematical structure:

$$\text{Stock}_s = \int_{t_0}^t (\text{Inflow}_s - \text{Outflow}_s) + \text{Stock}_0 \text{ (Eq.1),}$$

$$\text{Outflow}_s = \text{value of stock}_s / \text{average delay time (Eq.2),}$$

where the average delay time is the average amount of time that a material remains in the stock before it exits. In a first-order delay, the outflow is directly proportional to the stock. Our 30th order delay links 30 of these first-order delay structures in sequence so that the outflow of one stock is the inflow of another stock. The delay structure influences the distribution of outflows from a stock, and the 30th order delay was appropriate in this case to represent a range of maturation values (i.e., the delay structure creates the equivalent of a probability distribution of heifer maturation dates around the mean value). Nicholson and Stephenson (2014b) use a 100th order delay to represent a narrower distribution of maturation time at the U.S. dairy farms.

The number of cows for each farm-size category is treated as a productive asset and modeled using an “anchoring and adjustment” approach based on Sterman (2000). This mechanism assumes that desired cow numbers for each farm-size category respond non-linearly to expectations of future Net Farm Operating Income (NFOI) relative to a reference calibrated NFOI. Thus, the effect of expected NFOI on herd size follows a s-shape response (Figure A1 – Appendix A) in which, if NFOI/RefNFOI equals 1 the desired number of cows doesn't change from its current value. If this ratio is greater than 1, the desired cow numbers increases at a lower rate than the decreasing rate when NFOI/RefNFOI is between zero and 1. If NFOI/RefNFOI is negative the desired cows' number reduces smoothly reaching a minimum level. In this case, the “lookup function” is preferred to an exponential function because it avoids the calculation error when the basis assumes negative values and the exponent is between zero and one. The desired number of cows is smoothed by the parameter “long-term market observation adjustment time” assuring that short-time effects transmitted by the NFOI does not affect the farmer's

decision of herd adjustment. When the desired cow numbers changes, the voluntary culling rate is adjusted similar to the approach used by Chavas and Klemme (1986) and Gao et al. (1992).

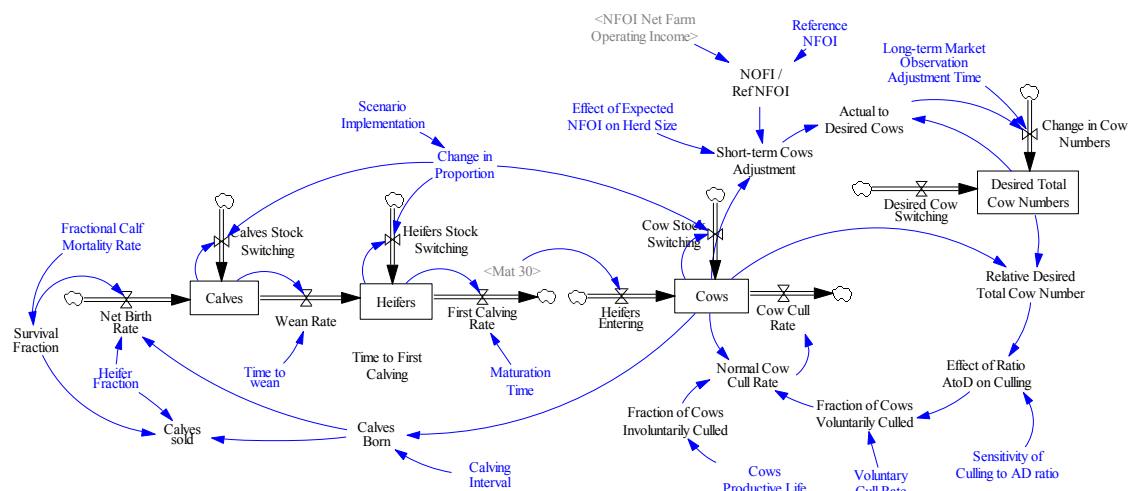


Figure 3 - Simplified visual representation of the herd aging chain stock-flow structure.

NFOI equals total revenues (milk plus animals sold) minus the exogenous variable costs of feeding, labor, and other expenses including cow's replacement cost (Figure 4). Feed cost comprises forage production and maintenance plus concentrated ration. The time-series price of soybean and corn were considered at the proportion of 40% and 60% respectively to estimate the concentrated ration price. Labor cost varies over time according to the monthly production per farm and the value of minimum salary annual adjustment. Other costs per month change according to the number of cows per farm and the calibrated inflation cost by year. The replacement cost was estimated as a fraction of the total monthly revenue. More details about these parameters can be seen in the Technology Improvements and Scenarios (section 3.5).

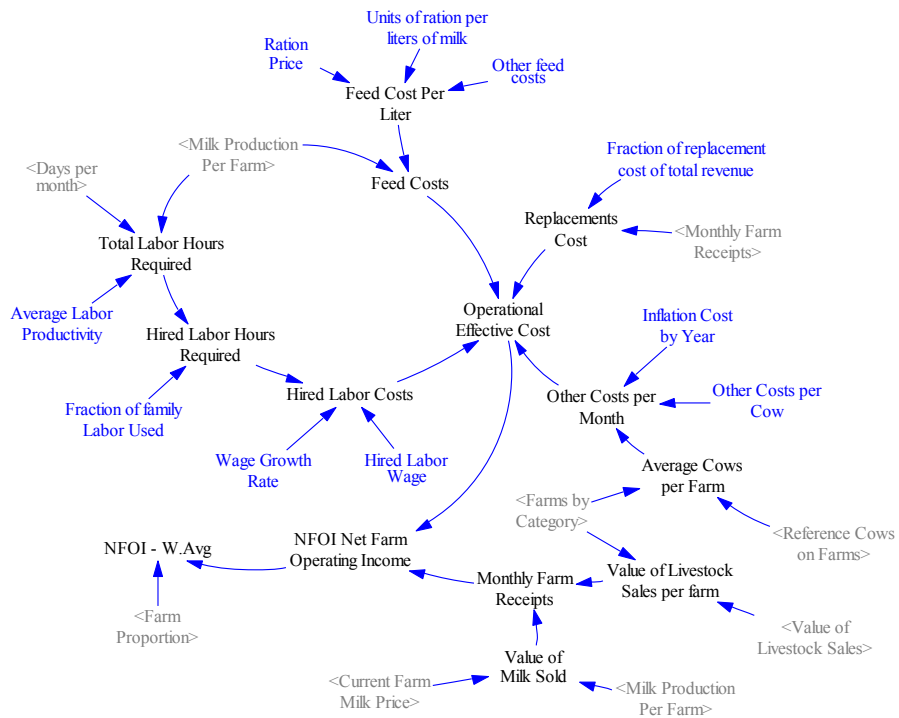


Figure 4 - Simplified visual representation of the Net Farm Operating Income structure.

Livestock sales are a secondary income component for dairy farming and are calculated by the number of animals sold times their market price. We assumed a direct correlation between beef price and cull cow price. Calf price is assumed as a fraction of the dairy cow cull price. Beef price varies exogenously according to official database time-series (Figure 5). Due the small proportion of slaughtered dairy animals in the total beef production in Brazil, the model assumes no effect of dairy cow cull rates on beef prices.

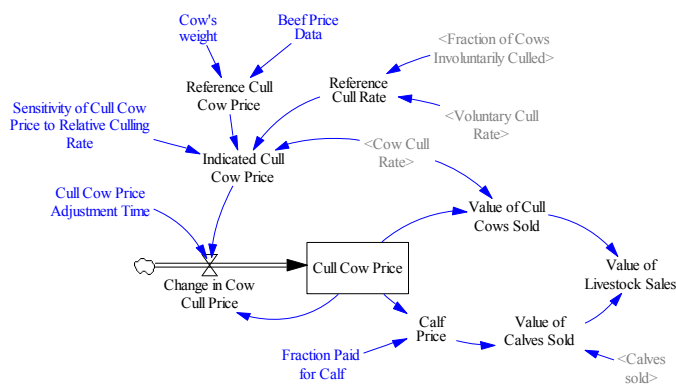


Figure 5 - Simplified visual representation of the Replacement cow price structure.

3.2. Milk Price

The expectation of the milk price paid to farmers is calculated by the volume-weighted average of the value of milk used as raw material by each dairy product category. The current price paid to farmers is adjusted with one-month delay representing

the required time to transmit the changes from processors to farmers. The stock and flow structure for the current farm price represents the adaptive expectations of the future price based on previous month (Figure 6).

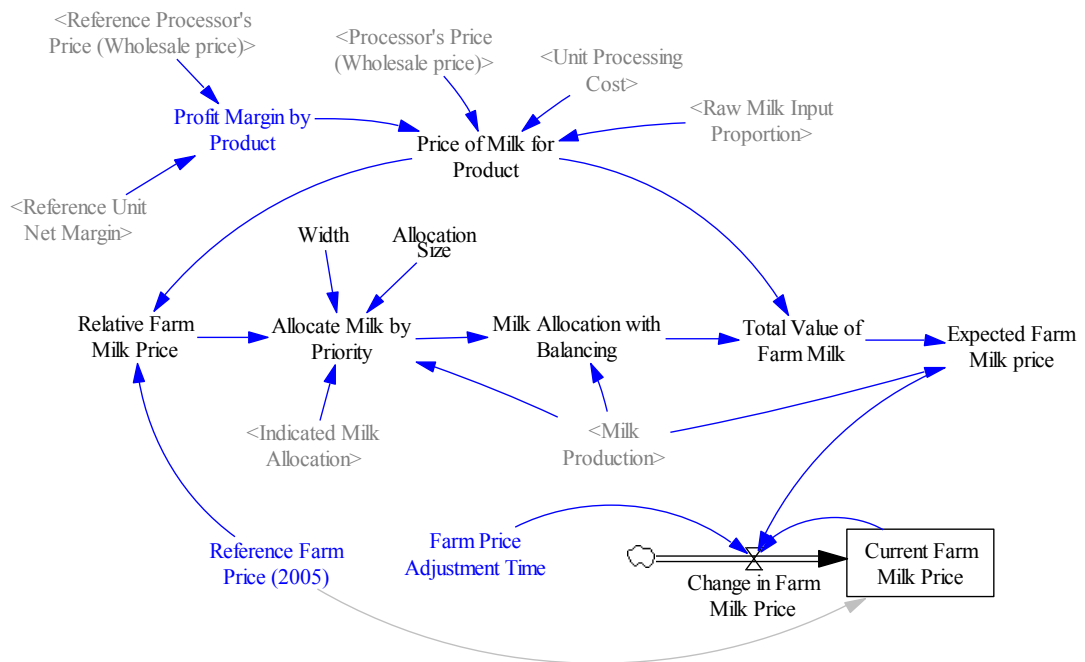


Figure 6 - Simplified visual representation of the milk price formation structure.

We used the function “Allocation by Priority” from the Vensim software² to allocate proportionally the farm milk production into four dairy categories (Fluid, Storable, Soft, and Balancing). This function is an algorithm that satisfies five desired properties: a) the quantity of dairy product must sum to the amount of farm milk production, under all conditions; b) all allocation must be positive; c) no dairy product should absorb more milk than its demand; d) under conditions of adequate farm milk production, each dairy product should receive exactly what it orders; e) under conditions of farm milk shortage, uniquely low-priority dairy products should receive very little or nothing and if there is a uniquely high-priority product with high demand, it should receive virtually everything, canceling other products. We also made a modification on the original formulation to satisfy the eventual surplus condition of farm milk, and thus, the milk allocated to balancing products was calculated by the total farm milk minus the sum of the milk allocated to fluid, soft, and storable products. The price of milk used in each dairy product was used as the proportional criteria to allocate the milk and was calculated considering the wholesale prices, the unit processing cost and the relative profit margin for each dairy

² A comprehensive description of the Allocation by Priority function can be found in the Vensim Help documentation.

product. As our scope is to simulate the national dairy industry, the model structure simplifies local price formation policies (payment by volume, quality, other bonus and penalties) representing the price as average reference market price. The current farm milk price affects both the milk-feed price ratio used to adjust milk production per cow and the NFOI which influences cow numbers.

The reference farm milk price to initiate the simulation was obtained by the national monthly average in 2005 from CEPEA database and all prices are expressed in nominal basis. When nominal price is used, the stakeholders (farmers, processors) can compare the simulation results with the observed prices from other economic sectors. Real prices (deflated prices) reflect the up-dated purchase power parity which is relevant to economist's assessments, but it doesn't correspond to the values often observed by market analysts, framers or milk buyers to make their current decisions.

3.3. Dairy Processing and Demand

A Supply and Utilization table (S&U) expressed in milk equivalents³ was formulated to balance the total milk production and the final demand of the main dairy products. The values were used as reference inputs to initialize the model. Based on the data availability and compatibility of sources, the dairy products were aggregated into four categories as follows: Fluid and Milk Beverages comprising UHT and a small amount of pasteurized fluid products; Soft Products with yogurt and ice-cream; Storable Products containing all kinds of cheeses, mainly mozzarella, *Requeijão* and *Doce de Leite*; and Balancing products containing powdered milk and Butter (Table 2).

³ The use of milk equivalents is not typically recommended for analysis of dairy product markets, because it ignores the separation of milk components that is ubiquitous in dairy processing, and the notion of joint products (such as butter and skim milk powder). Ignoring dairy components is justified in this case by the emphasis on farm-level technology analysis and the very limited data on dairy components available for Brazil. Future research should attempt to rectify this shortcoming of the present work.

Table 2 - Simplified version of the Supply and Utilization table of dairy products and milk equivalents in Brazil in 2005, units per month.

| | Production | Exports | Imports | Final demand* |
|---|---------------|------------|------------|---------------|
| <i>Quantity of product</i> | | | | |
| Soft products (kg) | 28,097,398 | 4,237 | - | 28,093,161 |
| Fluid and beverages (l) | 515,552,088 | 31,020 | 188,398 | 515,709,467 |
| Storable products (kg) | 37,673,402 | 949,796 | 280,592 | 37,004,198 |
| Balancing products (kg) | 100,140,570 | 5,428,363 | 2,899,455 | 97,611,662 |
| <i>Quantity of Raw Milk Used in liters</i> | | | | |
| Soft products | 24,444,736 | 3,686 | - | 24,441,050 |
| Fluid and beverages | 523,148,280 | 31,522 | 191,451 | 523,308,208 |
| Storable products | 289,774,155 | 8,876,900 | 2,975,025 | 283,872,280 |
| Balancing products | 519,655,079 | 28,888,278 | 26,855,539 | 517,622,341 |
| Total formal farm milk production | 1,357,022,250 | | | |

*Changes in stocks are typical components of an S&U table, required to calculate the final demand. However, these data are not available in Brazil, so stock changes are ignored in final demand estimates. We also did not include estimates of “intermediate” use of dairy products (that is, use of one dairy product to manufacture another dairy product).

Source: Elaborated by the author based on IBGE, MDIC and EMBRAPA.

As mentioned in the previous section, the farm milk production is allocated preferentially into different dairy product categories. The current formulation differs from the U.S. dairy model in Nicholson and Stephenson (2014b) that tracks skim milk and cream quantities to ensure the component balance between sources (farm milk) and uses (dairy product demand). Milk components (fat, protein, and solids) are the basis of farm price formation in U.S. and the government and processors (cooperatives) use this system to reduce the market information asymmetry. Due to the low degree of transparency for price transmission in Brazil and considering that our main objective is not centered on the processing sector analysis, we opt to use a conversion factor table to transform dairy products into milk equivalent obtained from EMBRAPA database.

The model structure for all product categories has the same functional structure, differing only by the relevant parameter values (Figure 7). The subscript function of Vensim was used to create this multidimensional structure. The inventories of each dairy product relative to sales (inventory coverage) are used to set the wholesale prices which in turn affects the dairy production and demand. Inventory stock level is controlled by production inflow and sales outflow and endogenously affects wholesale prices through relative inventory coverage. Wholesale price is transmitted to the retail sector assuming a markup pricing rule where the absolute value for each dairy product is exogenously

estimated observing the difference between processor and retailer prices, which is then adjusted based on specialist opinions.

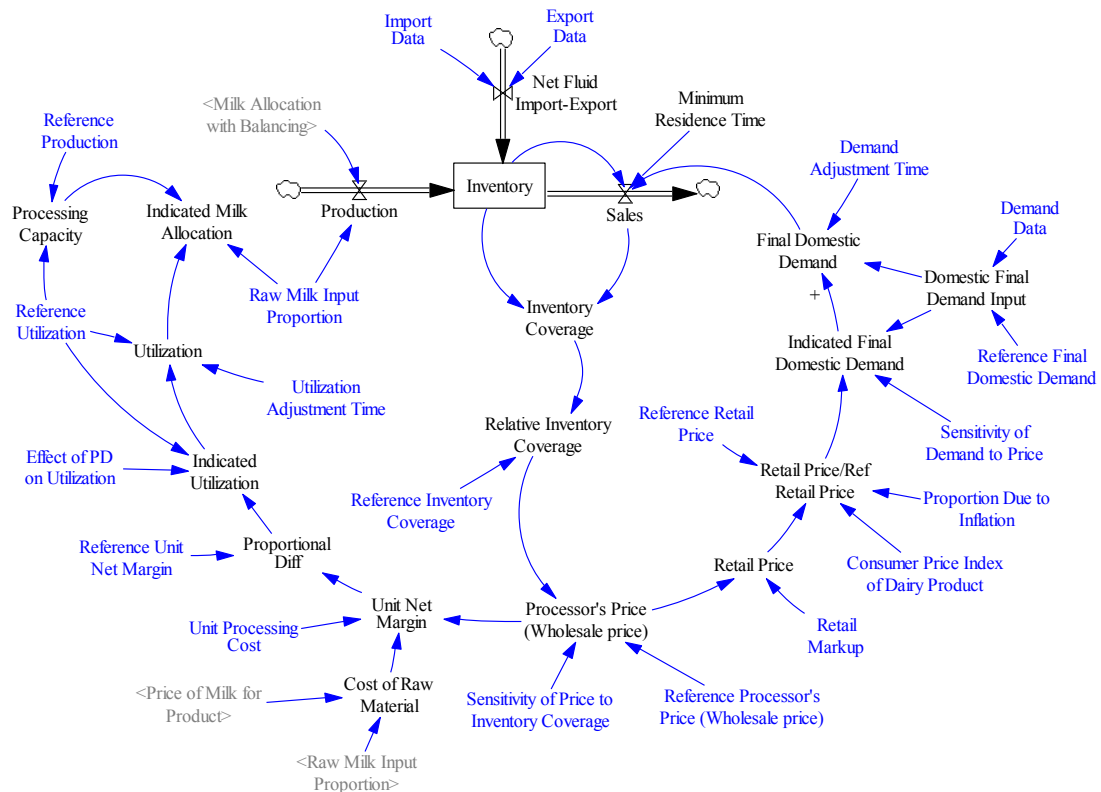


Figure 7 - Simplified visual representation of the dairy product supply-demand structure.

The demand for dairy products adjusts over time in response to relative retail price changes and takes into consideration the delays required for buyers to form price expectations, find substitutes, or for the expiration or renegotiation of contractual obligations with suppliers. Dairy product demand curves are assumed to shift exogenously over time based on data in the S&U tables from 2005 to 2016, representing increases in per capita consumption and population growth. The impacts of product prices on demand are modeled using constant-elasticity demand functions. The own-price elasticities of dairy products were specified based on values from the available literature as -1.501 for fluid and soft products, -1.164 for storable, and -0.863 for balancing products (see Table B2 in the Appendix B for Alves et al., 2007; Barbosa et al., 2014; Coelho et al., 2010; Coelho and Aguiar, 2007; Menezes et al., 2008).

Milk production over time is calculated endogenously by the farm supply component and incorporates the unit processing cost and unit net margin for each of the dairy product. In Brazil, publicly-available data about processing costs of dairy products are limited (most are proprietary) and non-systematic. Further, there is evidence that many dairy

processors would need to improve their accounting systems to make decisions based on more accurate cost information (Carli et al., 2012; Rezende et al., 2006; Scramim and Batalha, 1998). Thus, we used estimated values of processing cost and margins (excluding milk as raw material) based on available information from the U.S. dairy industry and Brazilian specialist opinions. The specialists pointed that soft products such as yogurts and deserts have the highest unit profit margin, followed by the balancing products (butter/powder) and primary commodities as mozzarella and UHT. Specialists also indicated that the rank order of product profitability is not fixed over time and there may be inversions depending on the current market prices, mainly between UHT and mozzarella cheese. In terms of volume, the UHT and mozzarella are the main drives of farm prices followed by other products such powder, butter, yogurt, and desserts. We used the official and consensus information to specify processing costs, which along with reference milk prices determined reference dairy product prices.

Finally, the model includes a simplified international trade component in which imports minus exports are exogenous inputs and expressed in the model as net exports. This is a simplified representation but is appropriate given the relatively small traded volumes and the limited relationship between Brazil and international dairy product prices (Nicholson and Novakovic, 2017). Thus, it seems likely that the potential effect of international trade on farm prices through changes in inventory levels is small, however, with the current version one may want to simulate assuming exogenous shocks. Large changes in milk production could change the relative prices of domestic and imported dairy products in Brazil enough to alter trade flows, but we ignored this effect in the current model formulation.

3.4. Model Behavior and evaluation

By definition, all models are wrong and represent a simplified version of the more complex reality of the world. Thus tests and procedures must be performed to check the suitability of the model for the purpose of the problem addressed, uncovering flaws, and improving the chances of the mode being used and useful. Sterman (2000) recommend 11 tests as best practices for SD models beyond the most common practice of the replication of historical data (Behavior Reproduction). These tests regard the appropriateness of the underlying assumptions, robustness, and the sensitivity of results to assumptions about model boundary and feedback structure. We undertook selected components of all 12 tests during model development and discuss in the following sub-sections.

3.4.1. Behavior Reproduction

System Dynamic models are not typically evaluated for their ability to predict specific values at specific times (termed “point prediction”) as are most forecasting models. This is because, for dynamic systems models, replication of the behavioral is a better indicator of model adequacy. Even a perfectly formulated dynamic system model (i.e., with correct structures and parameter values) can fail to point predict accurately in the presence of “noise”, that is, random perturbations or initial conditions errors (Sterman, 2000). In this sense, getting a model to fit the data well does not prove the model right but means the model cannot be rejected because of the data (see Vensim on-line documentation: *Section 18 – Optimization, Optional Modifying the Model*).

Replication of the reference mode behavior involves the model’s ability to mimic the trend and short-term variations of Farm Milk Price, Cow Numbers, and the monthly Formal Milk Production. We choose these variables as reference lines due to the data availability and because it is part of our interest variables of analysis. The Pearson correlation between the observed data and the Baseline simulation were 0.97 for the price, 0.98 for cow numbers and 0.87 for milk production (Figures 8, 9, and 10).

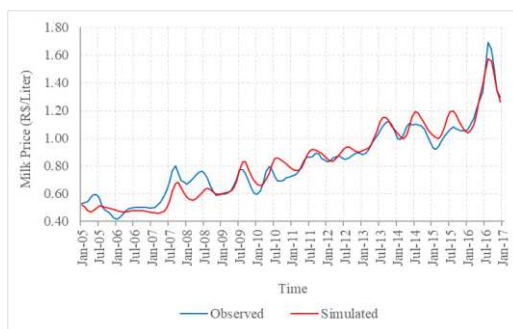


Figure 8 - Observed and simulated farm milk price in Brazil from January 2005 to December 2016.

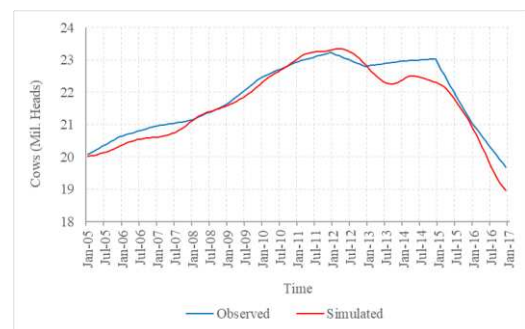


Figure 9 - Observed and simulated cow numbers in Brazil from January 2005 to December 2016.

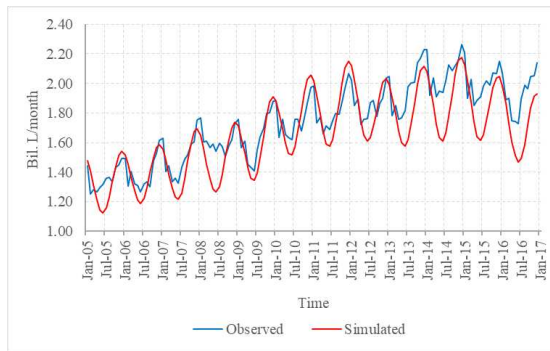


Figure 10 - Observed and simulated milk production in Brazil from January 2005 to December 2016.

3.4.2. Family Member

The family test asks whether the model can generate the behavior of other instances in the same class as the system the model was built to mimic. The more diverse the instance of a system a model can represent the more general the theory embodies. No formal analysis of other systems was undertaken. However, many results are consistent with those identified in previous studies of dairy farm technology adoption, including the potential for market effects of increased production to partially offset the farm-level benefits of technology adoption (as in Weersink and Tauer, 1990 and Zepeda et al., 1991). In addition, Albrecht (1992) and Parsons and Nicholson (2017) both note that technology adoption has the potential effect to concentrate the farm structure, with few larger farms producing a greater parcel of the total agriculture production.

3.4.3. Structure Assessment

The structure assessment test asks if the model is consistent with knowledge of the real system relevant to the purpose. Structure assessment focuses on the appropriate level of aggregation of the model, consistent rules with the behavior of the agents and if the model conforms to basic physical laws such as negative inventories (stocks) and prices. The system structure was developed based on previous models and literature, descriptive knowledge, statistical analysis of dairy industry data and through group discussions with specialists. During the development process, we conduct partial model tests of the intended rationality for the most relevant variables, for instance we tested an average Reference NFOI value for aggregated farm-size category and then modify it to different References NFOI for individual categories to represent more accurately the cow numbers dynamic. Disaggregation of the heifer stock into a high order delay (30th) was

another model structure optimization to represent the dispersion around the average maturation time in Brazil.

3.4.4. Integration Error

The SD simulation models are solved with a set of differential equations through numerical integration rather than the analytic solutions. Usually, traditional analytic solutions cannot be found in models with moderate realism and comprising a relatively high number of simultaneous equations. Differential equations are solved in a continuous-time using an infinitesimal time interval and the software calculates the integration of the stocks and the flows derivatives using discrete steps. Thus, the numerical integration finds the model solution by setting the time step that approximates to the continuous solution. Hence, all SD models have an intrinsic integration error that can be minimized according to the accuracy needed. We choose the Euler integration method to simulate the model. The Euler's integration is appropriated to most of models involving social and human systems because these models have naturally errors in initial conditions, parameters, historical data and model structure, and by comparison integration errors using Euler's method tend to be inconsequential. Engineering modelers may consider choosing a more precise integration method to gain the needed accuracy. A rule of thumb to find the best time-step that balances the trade-off between precision and computational capacity required is to reduce by half the time-step and assess the new the precision found, if it is close to the desired precision then the time-step can be set, if not, one more reduction can be made and reassess the error (Serman, 2000). The model time bounds range from January of 2005 to December 2016. The time step was set to 0.125 indicating that for every month the model makes 8 calculations ($1/0.125$). No relevant changes were noted by doubling or halving the time step. Results were recorded and exhibited once per month.

3.4.5. Dimensional Consistency

This is a basic test to check if each equation is dimensionally consistent. This test may reveal typographical error, inverted ratios or important flaws in understanding the structure or decision process. All equations were tested using routines from Vensim software to ensure consistent units and we avoided inclusion of arbitrary scaling factors with no real-world meaning and prudently introduced dimensionless parameters.

3.4.6. Parameter Assessment

This test aims to guarantee that all parameter values are consistent with relevant descriptive and numerical knowledge of the system. The parameters were obtained

observing previous models, previous literature, and official database. For some parameters of farm milk technologies in each category (mainly for improved technologies) we consulted 15 specialists from 8 national and international institutions and companies. The Vensim calibration routine was used to determine unavailable values consistent with known variables of interest like milk production, cow numbers, and farm milk price. Relevant calibrated parameters include: The Reference NFOI for each farm-size category, Sensitivity of Culling Rate to Desired Herd and Inflation Cost by Year (inflation effect on costs).

3.4.7. Behavior Anomaly

This test examines whether the anomalous behaviors result when assumptions of the model are changed or deleted. The anomalous behavior generated by deletion or modifications on structures provides evidence of its importance for the model purpose. Due to information asymmetry and lack of transparency in the dairy supply chain in Brazil, we had to test many formulations to represent the price formation and transmission from processors to farmers and retailers. We found the combination of the Allocation by Priority function and the fixed markup rules (see model description for further details on *Methods* section) the most efficient way to represent the price formation consistent with observed data and key informant descriptions. Different formulations resulted in unrealistic outcomes, although price formulation rules could benefit from additional detailed assessment and further information from market agents.

3.4.8. Sensitivity Analysis

Sterman (2000) recommends testing only parameters that the modeler suspects are highly uncertain and(or) are likely substantively affect the simulated numerical or behavioral outcomes. A parameter around which little or no uncertainty exists doesn't need to be tested. Likewise, if an uncertain parameter has little effect on the numerical outcomes it does not need to be tested even if its value is highly uncertain — because estimation errors are of little consequence. Most of the parameters were tested using the sensitivity analysis tool from Vensim. The model demonstrates numerical sensitivity in the sense that simulated results change in response to changes in a variety of assumed parameter values. However, the model was behaviorally sensitive primarily to changes in the parameters affecting the responsiveness of milk supplies to expected profitability – parameters controlling the herd aging chain. Alternative values of these parameters could generate very limited or very large oscillations that were not consistent with the behavior observed in the historical dataset of cow numbers, milk price, and milk production. This

is in accordance with tests performed in previous works of Nicholson and Stephenson (2014b).

3.4.9. System improvement

The test concerns to the capacity of the model to solve a real problem or if the model is able to suggest means to improve system outcomes. This evaluation is more typical of modeling efforts to support management changes, but the previous version of the model was tested by its potential to change mental models of stakeholders (specialists) about the impact of international trade on the Brazil farm milk price, e.g. when imports are zero out we found the farm price practically unchanged from the baseline behavior opposed to the more broadly commonsense and recent debate in specialized media.

3.4.10. Surprise Behavior

Discrepancies between model behavior and expectation are often on SD simulations and can be easily attributed to flaws in both the formal and mental models. However, occasionally the mental models (decision makers' conceptions about how the work works) may benefit from revision based on the outputs of SD models. (This is consistent with Sterman's definition of SD as a method to enhance learning in dynamically complex system). SD models have the capacity to generate previously unobserved or unrecognized behavior that is plausible but hard to identify due to complexity. Model analyses indicate that technology adoption can demonstrate dynamic complexity for instance, for small farms, technology implementation at slow rate results in a larger NFOI than the Baseline but then becomes lower (see Figure 18 in *Results* section).

3.4.11. Extreme conditions

The model should behave in realistic fashion no matter how extreme the inputs or policies are imposed on it. We tested each model equation during the building process and implement conditions to prevent errors when variable assumes zero value in ratios, constraints for non-negative values in inventories. For instance, with extreme higher demand the stocks of dairy products reduce very close to zero but never became negative. A very low farm profitability increases the culling rate, but the cow numbers remain non-negative.

3.4.12. Boundary adequacy

The most relevant concepts of the dairy market in Brazil were endogenized consistently with the generic commodity supply chain model. Technology adoption was

implemented as exogenous shocks allowing to isolate its impact on variables of interest. Other important variables for the supply-demand balance analysis such as demand trend, feed prices, and climate conditions were also exogenous. Modeling the causal structure for these exogenous variables is out of our scope and the introduction of additional feedback loops would not cause significant differences from the data we used for them.

3.5. Technological Improvements and Scenarios

As mentioned in the Methods and Data section, the main characteristics and initial parameters of milk production systems were obtained from the Dairy Livestock Survey of Minas Gerais of 2005 (Gomes, 2006). We then estimated technological improvements by changing the most relevant parameters based on other previous research (Camilo Neto et al., 2012; Fassio et al., 2006, 2005; Nascif, 2008; Oliveira et al., 2007), the EDUCAMPO⁴ database from SEBRAE-MG and specialists' opinion. Thus, the model retains the same five size categories (Table 1) but these are now separated into two technological levels: Non-adopters and Adopters. The subscript capability in Vensim was again a useful feature to associate the size categories with the two technological levels in the same structure. Thus, we specify in detail the characteristics of the technology for adopting-farms and assume relevant adoption rates without detailed consideration of the adoption process, then evaluate the market and profitability impacts of alternative adoption rates by different farm categories. In this section, we highlight the main assumptions made to estimate the improvements and describe the scenarios used to assess alternative pathways to technology transition. The detailed economic analysis of each farm-size category and technology level is provided on the Appendix D.

The initial herd size was considered the same for both technology levels in each category size and the model calculates endogenously the number of animals over time. It is worth noting that the model uses the official data from IBGE for the initial number of cows in milk, however, this data source does not differentiate the herd into categories (calves, heifers, dry cows), so we had to specify exogenously the parameters related to the herd dynamics such as calving interval, time to wean, cows productive life, average maturation time, mortality rate, proportion of cows in milk over the total cows and lactation period (Table 3).

⁴ EDUCAMPO is a management and technologic assistance program to dairy farmers from the Brazilian Micro and Small Business Support Service (SEBRAE). All data obtained from EDUCAMPO are classified and were used under permission.

Table 3 - Parameters of the herd aging chain used to simulate the technology improvement, five farm-size categories.

| Parameter by system size | Non-adopters | Adopters |
|--|---------------------|-----------------|
| <i>Time to wean (months)</i> | | |
| <50 | 4.8 | 3.5 |
| 51-200 | 4.0 | 3.0 |
| 201-500 | 3.5 | 2.5 |
| 501-1000 | 2.9 | 2.5 |
| >1000 | 2.4 | 2.0 |
| <i>Cows in milk/total cows (percentage)^a</i> | | |
| <50 | 61.5 | 75.0 |
| 51-200 | 64.5 | 75.0 |
| 201-500 | 65.2 | 75.0 |
| 501-1000 | 69.0 | 77.0 |
| >1000 | 75.1 | 80.0 |
| <i>Lactation period (months)</i> | | |
| <50 | 8.0 | 9.5 |
| 51-200 | 9.0 | 9.5 |
| 201-500 | 9.0 | 9.5 |
| 501-1000 | 9.5 | 9.5 |
| >1000 | 10.0 | 10.0 |
| <i>Calving interval (months)*</i> | | |
| <50 | 13.0 | 12.7 |
| 51-200 | 13.9 | 12.7 |
| 201-500 | 13.7 | 12.7 |
| 501-1000 | 13.7 | 12.3 |
| >1000 | 13.3 | 12.5 |
| <i>Heifer fraction born (percentage)</i> | | |
| <50 | 50.0 | 60.0 |
| 51-200 | 50.0 | 60.0 |
| 201-500 | 55.0 | 63.0 |
| 501-1000 | 60.0 | 65.0 |
| >1000 | 60.0 | 65.0 |

^a Percentage of cows in milk is not directly considered as a model input but reflects the change in the calving interval and is thus reported as an additional indicator of modifications to herd population and productivity changes.

Time to wean was reduced proportionally observing the value of two months as a benchmark set by the most efficient system. To be economically consistent with the time to wean reduction, the artificial milk feeding cost was increased up to the proportion of 1.6% (based on the most efficient size) of the total cost in all systems. It incorporates proportionally the number of cows in milk and a multiplicative factor related to technological improvement. Cows in milk over total cows and the respective lactation period were not directly considered as a model input, however, these were considered through assumptions about the calving interval⁵. We assumed that farmers increase their use of artificial insemination by increasing its cost up to the limit of 1.5% of the total milk revenue matching the reference value of the most efficient system. The heifer fraction born was also increased assuming that farmers adopt partly the sexed semen. Once we

⁵ Calving interval= (Cows in milk/Total cows)/Lactation period

are assessing the impact of technologies that affect directly the milk production per cow (feed strategy and genetic gains) the other parameters that affect the herd aging chain like calf mortality, maturation time of heifers (time to first calving) and cows productive live were not changed from non-adopters to adopters.

The average total area used by each five size categories are 24.9, 53.2, 86.7, 122.1 and 258.8 hectares, respectively, and these values were kept constant for non-adopters and adopters. However, we changed the land use considering the herd feed strategy and nutritional needs. The areas of sugar cane, supplementary forage and corn silage were adjusted differently in each size category to match the herd consumption per day in terms of dry matter intake per head, changes in seasonal availability of feeds during the year and the productivity per hectare. The operational costs associated with each forage type were increased proportionally based on the estimated planted area adjusted by a multiplicative coefficient to represent technology improvement. The pasture maintenance cost was also increased proportionally to the stocking rate for cows in milk and by a multiplicative technology improvement coefficient representing the implementation of pasture rotation and higher level of fertilizer utilization. The maintenance cost of each forage type was updated in a separate spreadsheet and inputted into the model structure through the parameter for *Other feed costs* (Table 4).

Table 4 - Forage area and other feed costs used to simulate the technology improvement in each size farm category.

| Parameter by system size | Non-adopters | Adopters |
|--|---------------------|-----------------|
| <i>Sugar cane area and productivity (ha & ton/ha)</i> | | |
| <50 | 0.7 | 2.2 |
| 51-200 | 1.3 | 2.9 |
| 201-500 | 2.2 | 4.7 |
| 501-1000 | 2.8 | 4.1 |
| >1000 | 8.8 | 8.8 |
| <i>Silage area (ha & ton/ha)</i> | | |
| <50 | 0.5 | 0.0 |
| 51-200 | 1.7 | 3.0 |
| 201-500 | 5.3 | 5.2 |
| 501-1000 | 13.3 | 15.8 |
| >1000 | 28.9 | 36.0 |
| <i>Supplementary grass area (ha & ton/ha)</i> | | |
| <50 | 0.7 | 2.1 |
| 51-200 | 1.2 | 2.2 |
| 201-500 | 1.2 | 3.7 |
| 501-1000 | 2.0 | 4.3 |
| >1000 | 3.2 | 9.4 |
| <i>Pasture area* (ha & ton/ha)</i> | | |
| <50 | 23.0 | 20.6 |
| 51-200 | 49.0 | 45.0 |
| 201-500 | 78.0 | 73.0 |
| 501-1000 | 104.0 | 97.9 |
| >1000 | 218.0 | 204.5 |
| <i>Other feed costs** (R\$/year; R\$/Liter)</i> | | |
| <50 | 689; (0.054) | 1,026; (0.048) |
| 51-200 | 2,652; (0.059) | 6,495; (0.076) |
| 201-500 | 7,422; (0.065) | 11,496; (0.057) |
| 501-1000 | 17,869; (0.069) | 26,816; (0.065) |
| >1000 | 64,401; (0.084) | 96,248; (0.084) |

*Estimated by the difference between the sum of all cultivated area less the average pastures area. **Does not include concentrated ration cost.

The consumption of concentrated ration per cow was increased proportionally to the milk production per cow per day and took into consideration the difference of nutrients supplied by the forage during the dry and rain season of the year (Table 5).

Table 5 - Recommendation of concentrated ration per cow per day based on milk production and the period of the year.

| Cow production (L/cow/day) | Ration use (kg/cow/day) | |
|-------------------------------|----------------------------|------------|
| | Rain season | Dry season |
| 3 to 5 | - | 1.0 |
| 5 to 8 | 1.0 | 2.0 |
| 8 to 11 | 2.0 | 3.0 |
| 11 to 14 | 3.0 | 4.0 |
| 14 to 17 | 4.0 | 5.0 |
| 17 to 20 | 5.0 | 6.0 |

Source: EMBRAPA Southeast Livestock.

Based on the recommendation above, we estimated the milk production and ration consumption month by month in a spreadsheet (details are provided in Appendix C) and consider the average ratio of kilograms of ration per liter of milk produced as an appropriate parameter value for each system and technology level (Table 6).

Table 6 - Average ratio of concentrated ration consumption per liter of milk produced.

| System size (Liters/day) | Non-adopters (Kg/Liter). | Adopters (Kg/Liter). |
|-----------------------------|-----------------------------|-------------------------|
| <50 | 0.183 | 0.182 |
| 51-200 | 0.296 | 0.283 |
| 201-500 | 0.334 | 0.262 |
| 501-1000 | 0.351 | 0.264 |
| >1000 | 0.351 | 0.288 |

We assume a genetic gain that changes the herd composition identified by Gomes (2006) increasing the participation of Holstein breed over the Zebuine and non-defined breed cows (Table 7).

Table 7 - Percentage of cows on herd considering the breed composition used to simulate the technology improvement in each size farm category.

| System size (Liters/day) | Non-adopters | | Adopters | |
|-----------------------------|--------------|---------|----------|---------|
| | H:Z | Z & NDB | H:Z | Z & NDB |
| <50 | 58 | 42 | 70 | 30 |
| 51-200 | 67 | 33 | 75 | 25 |
| 201-500 | 71 | 29 | 80 | 20 |
| 501-1000 | 83 | 17 | 90 | 10 |
| >1000 | 96 | 4 | 96 | 4 |

H:Z – Holstein zebuine cross breed. Z – Zebuine. NDB – Non-defined breed.

The effect of the simulated genetic gains and the feed strategy adequacy are reflected on the estimated milk production per cow and affects the seasonal amplitude of milk per cow (Table 8). To simulate the observed milk production seasonality at the current technology level we adapted a cosine function with a calibrated seasonality

amplitude parameter. For the adopters in each size-farm category the parameter was scaled to match the assumed average, maximum and minimum milk production per cow. We took into consideration specialist opinion and followed the logic that the higher the investment on feed system and genetic potential will lower the amplitude of seasonal variation in milk per cow. The most productive farm category was considered as a benchmark for the minimum seasonality amplitude. This approach seems sufficient for the propose of our main objective, although, one could obtain a more precise seasonality outcome if a detailed climatic and nutritional component is introduced into the model structure as in Cristóbal-Carballo (2009) and McRoberts et al. (2013).

Table 8 - Milk production per cow and seasonality* used to simulate the technology improvement in each size farm category.

| System size (Liters/day) | Non-adopters (Liters/cow/day) | | | | Adopters (Liters/cow/day) | | | |
|-----------------------------|----------------------------------|------|------|-------|------------------------------|------|------|-------|
| | Max. | Min. | Avg. | Seas. | Max. | Min. | Avg. | Seas. |
| <50 | 6.3 | 2.4 | 4.3 | 0.45 | 7.8 | 4.2 | 6.0 | 0.30 |
| 51-200 | 8.22 | 3.96 | 6.1 | 0.35 | 12.5 | 7.5 | 10.0 | 0.25 |
| 201-500 | 10.3 | 6.2 | 8.2 | 0.25 | 15.0 | 10.0 | 12.5 | 0.20 |
| 501-1000 | 12.6 | 8.4 | 10.5 | 0.20 | 17.3 | 12.8 | 15.0 | 0.15 |
| >1000 | 14.9 | 10.8 | 12.9 | 0.16 | 20.7 | 15.3 | 18.0 | 0.15 |

*Seasonality = $[(\text{Max}/\text{Avg.}) - 1]$ or $|[(\text{Min}/\text{Avg.}) - 1]|$

The replacement cost of cows was adjusted from non-adopters to adopters proportionally to the ratio of milk revenue over total revenue (including animal sales). Other costs per cow including machinery and building maintenance, transportation cost, energy, taxes, and medicaments were increased proportionally to the milk production per year.

Finally, labor is an important cost associated with many of technological parameters, for instance, time to wean reduction would increase the labor cost specially to systems that must make the transition from natural to artificial milk feeding. However, we chose to model the labor cost endogenously influenced by the milk production and by a labor efficiency parameter of 64, 121, 194, 297 and 525 liters per person per day over the five-size farm category, respectively. Family labor availability was maintained constant and the hired labor was proportionally increased when the milk production exceeds the family labor capacity. The percentage of family labor used in each system was 89, 65, 49, 30 and 25 in each size category and constant for both tech levels.

The simulation model allows simulation of numerous scenarios to assess technology adoption outcomes. We defined a relevant subset of this large number of possibilities, assessing six scenarios considering three different transition rates from non-adopters to adopters for two farm-size categories (small and large) (Table 9).

Table 9 - Six scenarios description considering the size category and the rate of transition from Non-adopters to Adopters.

| Farm size | Adoption Rate (% per year) | | |
|-----------------------|----------------------------|---------------|------------|
| | Slow (0.3) | Medium (1.65) | Fast (3.0) |
| Small (<200L per day) | SS | SM | SF |
| Large (>200L per day) | LS | LM | LF |

Adoption is often considered related to farmers' personal attributes, production scale, the perceived attributes of the technology, social interaction and other factors (Thirunavukkarasu and Narmatha, 2016; Verner and Gubbels, 1967). Rogers (2003) provides a comprehensive argument about diffusion of innovation and classifies farmers into five stages of adopters: innovators, early adopters, early majority, late majority and finally the laggards emphasizing that the diffusion process follows a s-shaped curve over time, similar to our transition technology improvement structure. The early adopters are more likely to be literate, have more years of formal education, have higher social status, are wealthier and have larger-sized units than later adopters, which is the most important characteristic that justify the scenarios assumption. Despite the socioeconomic status and innovativeness appear to go hand in hand, there is no clear conclusion about the cause-and-effect relation between these two variables. For instance, some types of technology, like pasture fertilization and irrigation, are costly to adopt and require large initial amounts of capital. Thus, only farmers with relatively high economic efficiency have enough resources or can get access to bank loans to adopt this type of technology. Further, due to the risk associated to innovation process, wealthy and bigger farmers have higher capacity to deal with the probability of failure during the innovation process. Our model is not focused on the underlying causes of the innovation process but to understand the market and socioeconomic effects of differences in technology adoption by different farm-size categories. Thus, the first set of scenarios are interested in simulating the market outcomes and the farm financial impact of increasing the economic efficiency of small farms, whereas the second set of scenarios assesses impacts if the largest farms make a transition to more efficient production systems considering different rates of adoption in each case.

As mentioned in the previous section, the small farm category represents a large proportion of the total farms in the Brazilian dairy sector and an important economic activity to retain families in rural areas by providing a minimum monthly income. Many policies have been executed by the federal and state governments to help small dairy family farms to continue their business. A variety of programs can be cited and most of

them are focused on free technical assistance by extension agencies, food acquisition program by the government, educational and training programs, and subsidized interest rate for investment loans. In general, the main objective of the governmental programs is to increase the milk production and the economic efficiency of the small family farms. Our model does not examine the impacts of these specific support programs, but rather can be used to assess the impact on market conditions in terms of milk price levels and economic performance on the long and short-term if small dairy farms perform a transition to higher efficiency level (SS, SM, and SF).

Evidence from previous studies indicates that technology diffuses very slowly among dairy farmers in developing countries, with estimates ranging from 0.5% to 2.5% per year depending of the nature of the technology. In environments of more developed dairy industry the speed of diffusion can be faster, ranging from 6% to 21% per year (Batz et al., 1999). It is worth noting that adoption of new practices in dairy production systems is rarely dissociated from other current practices and thus measurement of the impact of individual practices can be challenging (Khanal et al., 2010). Thus, for our purpose, we considered the technology improvements on dairy systems of the adoption of a set of practices (sometimes termed a “technology package”) at rates ranging from 0.3 to 3% of farms per year. Finally, it is important to clarify that we do not include an assessment of any transition costs that would be incurred by farms for the assumed technology transition.

A careful reader may note at the model representation (Figures 2 and 3) the presence of variables associated with the switching flows. This is a mathematical formulation that allows the transition of calves, heifers, cows, and farms (consequently all associated variables) from the non-adopters to adopters when a positive rate over time is set by the parameter Change in Proportion. The subscript function from Vensim allows us to write more than one equation for each of these flows, for instance, the flow Cow Stock Switching is represented by:

$$\text{Cow Stock Switching}[\text{Size, Non-adopters}] = \frac{-\text{Cows}[\text{Size, Non-adopters}] \times \text{Change in Proportion}[\text{Size}]}{\text{Time Step}} \quad (\text{Eq.3})$$

$$\text{Cow Stock Switching}[\text{Size, Adopters}] = \frac{+\text{Cows}[\text{Size, Non-adopters}] \times \text{Change in Proportion}[\text{Size}]}{\text{Time Step}} \quad (\text{Eq.4})$$

where the values between brackets represent the subscripts associated to the farm-size category and technological level respectively. Thus, the Change in Proportion for each category size is the parameter used to generate the scenarios analysis described on the next section.

Given the constant proportional rate of technology adoption assumed for each scenario, the proportion of farms adopting a technology follows an increasing but goal-seeking behavior, and the final proportion of farms in each technology category can easily be calculated (Table 10). The proportion of farms in each size and technology category over time (Figure 11) are used as the weights to calculate the weighted average of some variables that describe overall industry performance, such as milk production, NFOI, number of cows.

Table 10 - Percentage of total farms adopting technology* by category in each scenario at the end of simulation period (December 2016).

| Category/Scenario | Base | SS | SM | SF | LS | LM | LF |
|--------------------------|-------------|-----------|-----------|-----------|-----------|-----------|-----------|
| <50 Liters/day | | | | | | | |
| Non-adopters | 44.0 | 26.1 | 2.5 | 0.2 | 44.0 | 44.0 | 44.0 |
| Adopters | - | 17.9 | 41.5 | 43.8 | - | - | - |
| 51-200 L/day | | | | | | | |
| Non-adopters | 35.4 | 21.0 | 2.0 | 0.2 | 35.4 | 35.4 | 35.4 |
| Adopters | - | 14.4 | 33.4 | 35.2 | - | - | - |
| 201-500 L/day | | | | | | | |
| Non-adopters | 14.0 | 14.0 | 14.0 | 14.0 | 8.3 | 0.8 | 0.1 |
| Adopters | - | - | - | - | 5.7 | 13.2 | 13.9 |
| 501-1000 L/day | | | | | | | |
| Non-adopters | 4.0 | 4.0 | 4.0 | 4.0 | 2.4 | 0.2 | 0.0 |
| Adopters | - | - | - | - | 1.6 | 3.8 | 4.0 |
| >1000 L/day | | | | | | | |
| Non-adopters | 2.6 | 2.6 | 2.6 | 2.6 | 1.5 | 0.1 | 0.0 |
| Adopters | - | - | - | - | 1.1 | 2.5 | 2.6 |

*The values reported are the proportions of total farms in each size and technology category, not the proportions of farms in each size category that have adopted the technology. The analysis assumes no change in proportions of farms in each size category over time.

The stock and flow structure used in the transition between non-adopters and adopters generates a behavior similar to a logarithmic function (hence, goal-seeking behavior in the SD terminology). This differs from the logistic function used to explain the diffusion behavior over time proposed by Rogers (2003) (S-shaped growth function) and empirically tested inclusive on dairy sector (Chapman et al., 2009; Diederer et al., 2003). However, the simpler goal-seeking formulation applied in this analysis is appropriate because the focus is on impacts given assumed rates of adoption, not on adoption processes *per se*.

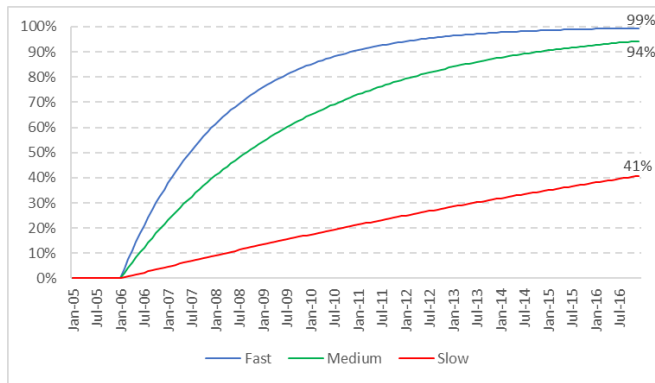


Figure 11 - Cumulative proportion of farmers adopting the improved technology system over time and the final proportion at the end of simulation period.

4. RESULTS

4.1. Presentation

The results are divided into three sections to facilitate the interpretation and highlighting complementarities. First, the temporally-aggregated results for aggregated farm categories is presented, then the temporally-aggregated results for individual farm categories, and finally the temporally-disaggregated results for individual farm categories. The discussion of the main outcomes and comparisons to previous works are made in a separated sub-section.

4.1.1. Temporally-aggregated Results for Aggregated Farm Categories

We initially discuss the temporally-aggregated effects of technology adoption (Table 11 and 12), because these provide a broad assessment of key farm- and market-level outcomes. The first main outcome of the aggregated analysis is that technology adoption results in larger average milk per cow and annual milk production for all scenarios even when cow numbers are decreased. Milk production increases more with faster rates of adoption. In the scenarios which small farms improve their technology (SS, SM, SF) the average annual milk production increased (from 5% to 14%) due to increases in milk per cow (7% to 26%), which more than offset the average decrease in cow numbers (-2% to -9%). On the other hand, in the scenarios which larger farms improve their technology (LS, LM, LF) the average annual milk production increases (6% to 21%) due to increases in both milk per cow (3% to 12%) and cow numbers (2% to 8%).

Table 11 - Average values of aggregated farm-related outcome variables for the six scenarios of technology improvement and the difference percentage from Baseline, average from January 2006 to December 2016.

| Outcome Variable, Type of Result | Baseline | SS | SM | SF | LS | LM | LF |
|--|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Outcome | | | | | | | |
| Milk production (bil. L/year) | 27.2 | 28.7 | 30.5 | 31.0 | 28.8 | 32.0 | 32.9 |
| Cows (Mil. Heads) | 21.8 | 21.4 | 20.1 | 19.8 | 22.3 | 23.3 | 23.7 |
| Milk per cow (L/cow/year) | 1,247 | 1,340 | 1,517 | 1,569 | 1,290 | 1,373 | 1,392 |
| Farm milk price (R\$/L) | 0.85 | 0.82 | 0.77 | 0.76 | 0.82 | 0.76 | 0.74 |
| Farm price variation (CV) | 0.31 | 0.23 | 0.31 | 0.32 | 0.29 | 0.28 | 0.27 |
| Average NFOI (R\$/farm/month) | 1,013 | 927 | 793 | 752 | 1,410 | 1,826 | 1,763 |
| Percentage difference from Baseline | | | | | | | |
| Milk production (%) | - | 5.5 | 12.3 | 14.0 | 5.7 | 17.8 | 21.1 |
| Cows (%) | - | -1.9 | -7.7 | -9.4 | 2.1 | 7.0 | 8.4 |
| Milk per cow (%) | - | 7.5 | 21.7 | 25.9 | 3.5 | 10.1 | 11.7 |
| Farm milk price (%) | - | -3.7 | -9.5 | -10.9 | -3.4 | -10.2 | -12.8 |
| Farm price variation (%) | - | -3.7 | 0.0 | 2.4 | -6.9 | -10.8 | -11.7 |
| Average NFOI (%) | - | -8.4 | -21.7 | -25.7 | 39.2 | 80.2 | 74.1 |

Total milk production and production per cow increase in all scenarios because the model assumes exogenously higher maximum potential production per cow (+40%) with technology adoption and because of the general increase of the milk-feed price ratio that adjusts the production practices. The adjustments via milk-feed price ratio comprise the response to a general increase in farm milk prices over time relative to an exogenous concentrated ration price (one of the most important cost components). For example, when adoption rate is fast in scenarios SF and LF the milk-feed price ratio increases on average 8% and 21% for small and larger farms, respectively. These effects offset reductions in cow numbers when small farms adopt new technology, discussed further below.

However, overall average milk per cow increases more when small farms adopt technology than when large farms do. This is due to in large part to the assumption about the initial number of cows in each farm-size category; 80% of farms (46% of cows) are initially in the small category. For example, if small farms adopt technology as in scenario SS, SM, and SF, this would result in a large productivity increase for 80% of farms and a decrease (due to lower milk prices and profitability) for 20% of farms. Thus, the resulting effect on average milk per cow is larger than if 20% of farms increase milk production per cow and 80% decline as observed when large farms adopt in scenarios LS, LM, and LS (Table 11).

The disaggregated analysis, better explored in the next section, helps to understand the net-effect of technology adoption on cow numbers and milk production per cow when farms are separated into groups of technology adopters and non-adopters. There are trade-offs between adopters and non-adopters, indicating that if one set of farmers chooses to innovate, adoption can improve their productivity and financial performance but will also generally worsen the outcomes for non-adopting farms. For example, when farms of up to 50 liters per day and 51-200 liters per day adopt technology at the fastest assumed rate, they increase milk production per cow by 36% and 58% respectively, which causes a reduction of about -2% on farms of the same size category who do not improve their systems and on the three largest farm size categories. The negative effects arise due to increased overall milk production and lower average prices for all farms.

Total cow numbers are increased in scenarios where large farms adopt and decreased when small farms adopt technology. This outcome is related to the underlying structure of the model in which herd size is endogenously driven by long-term farm profitability (NFOI) and farmers' decisions about the desired voluntary culling rate. In all scenarios which small farms adopt technology (SS, SM, and SF), although NFOI

increases for adopting small farms, the average NFOI for all farms is lower than in the *Baseline*, indicating that the benefits of production efficiency gains experienced by adopting farms do not compensate, at the aggregate level, for the milk price reduction (of -4% to -11%) and reduced NFOI for non-adopters caused by the increased milk supply. When small farms adopt technology at any rate, it reduces the average NFOI of all farm sizes for non-adopters (except the <50) and this effect is enough to reduce overall cow numbers. When large farms adopt technology, the positive impact on profitability for adopters is sufficiently large that these farms have an incentive to increase cow numbers, and their increase more than offsets the decrease for small farms.

Rates of adoption also affect overall average farm profitability, albeit with some differences in the pattern of responses as adoption rates increase. For the scenarios in which small farms adopt improved technology, the percentage decrease in overall average NFOI is larger as adoption rates increase, although the change is relatively small when the rate increases from that used in the SM scenario to that for the SF scenario. For the LS, LM, and LF scenarios, the annual average NFOI increases by 39%, 80%, and 74%, respectively. The larger change for the LM scenario, when larger farms adopt at a medium rate, arises because the faster adoption in the LF scenario increases milk production more rapidly, with a larger negative effect on milk prices and farm revenues. This is evidence that profitability outcomes depend not only on the decision of adopting or not technology and in which size category technology is promoted, but also on the rate of adoption over time.

The average farm milk price is 3% to 13% lower when compared with the *Baseline* in all scenarios due to the increase in milk supply. For scenarios in which either small or large farms adopt, the faster the adoption rate, the lower is the average farm milk price. This reduction in producer price is a common result of the adoption of agricultural technologies that increase productivity and suggests that the benefits of adoption will be experienced at least in part by post-farm supply chain participants (processors, retailers and consumers).

Price variation is lower when large farmers improve their systems (LS, LM, and LF) than when small farmers do (SS, SM, and SF), although the reduction is probably not substantively important for farm management decisions. The average coefficient variation (CV) for farm milk price is smaller when large farms improve their systems (0.28) than when small farms do (0.31). However, the observed changes on CV are relatively modest, with a maximum reduction of 12%. Price variation is partially associated with the exogenous milk production seasonal component that is set to reduce

with technology adoption and with endogenous change over-time. Increased milk production with technology adoption also slows the rate of milk price increase over time, which is reflected in a lower average milk price and lower overall CV. Thus, the lower CV most likely reflects long-term pattern changes and not the short-term seasonal component.

In scenarios with large farms adopting technology, price variation decreases as the rate of adoption increases. When small farmers adopt technology the price variation decreases 3.7% for the slow rate (SS), remains the same for the medium adoption rate (SM) and becomes 2.4% higher at a fast rate (SF). The unexpected increase for the SF scenario is due to a smaller reduction in standard deviation compared to the reduction in the mean, and probably has no significant implications in terms of farm management risk.

Consumers benefit with technology adoption because of the supply increase and price reduction at retail level. Prices paid by processors to farmers are transmitted from wholesale to retail sector under the assumed markup pricing rules (Table 12). However, farmers experience larger price reduction than the wholesale and retail sectors. Prices are smoothed at the retail level compared to the farm level because of the assumed delays in adjusting processing utilization in response to changes in profitability and quantity demanded in response to product price changes. Price decreases for consumers are larger with faster technology adoption, but the response is non-linear; the largest marginal effect is observed with a change from the slow- to medium- adoption rate (SS to SM or LS to LM). Percentage reductions in retail prices are similar when small or large farms adopt technology.

Retailers experience gains in both total sales volume and revenues for any rate of technology adoption on farms, although the increases are larger for faster adoption rates and when larger farms adopt technology. The increase in sales (quantity demanded) is due to lower retail prices given the assumed own-price elasticities of demand and increased revenues (prices times quantities) result from elastic demand which implies that revenues increase when prices decrease.

Table 12 - Aggregated average of the percentage difference from the Baseline for wholesale price, retail price, product sale and value of retail sale of dairy products.

| | Baseline | SS | SM | SF | LS | LM | LF |
|---------------------------|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Farm milk price (%) | - | -3.7 | -9.5 | -10.9 | -3.4 | -10.2 | -12.8 |
| Wholesale Price (%) | - | -2.4 | -5.2 | -5.9 | -2.1 | -5.4 | -6.4 |
| Retail Price (%) | - | -1.3 | -3.0 | -3.4 | -1.2 | -3.0 | -3.7 |
| Product Sales (%) | - | 3.4 | 7.2 | 8.2 | 3.4 | 10.3 | 12.0 |
| Value of Retail Sales (%) | - | 2.0 | 3.8 | 4.3 | 2.2 | 6.7 | 7.5 |

The aggregated dairy products analysis is consistent with the expected effect of farm milk supply-demand balance on price changes throughout the supply chain. Although the focus here is on aggregated price changes, more detailed reporting of disaggregated outcome by dairy products can be found on Table E1 and E2 on Appendix E. However, it is worth noting that balancing products have the largest relative change in prices when compared with other dairy products, especially on scenarios with medium and fast adoption rates. This difference is due to the assumptions of the Allocation by Priority function, which weights the average farm milk price by the volume of each dairy product (Equation 132, Table A6 on Appendix E). As mentioned in the *Methods and Data Description* section, the modification made on this function assumes that all milk supply surplus produced by farmers that is not absorbed by the internal consumption as Fluid, Soft or Storable product is allocated to Balancing products that comprise butter and powder milk. In the case of SM, SL, LM and LF scenarios, technology improvement generates additional farm milk supplies that increase the inventories of Balancing more than the other dairy products under the assumed allocation mechanism, resulting in a larger product price reduction. This assumption about surplus milk allocation does not fully reflect the relative product price relationships in Brazil, but due to limited information regarding allocation mechanisms at the micro level and basic price and cost data for dairy processing, our assumptions appear to provide a reasonable representation of the aggregated market effects.

Thus, the overall impacts of technology adoption include increased aggregate milk production, financial benefits from adopting farms, often decreased incomes for non-adopting farms, and lower and somewhat less variable farm milk prices. Lower farm milk prices are reflected in lower wholesale and retail product prices, higher quantities processed and demanded, and increased revenues for dairy product retailers. These effects are generally consistent with what would be expected in an aggregate sense, with a key result being that the benefits accrue not only to farmers but to other organizations in the dairy supply chain. In addition, although in a qualitative sense many of the effects of adoption are similar across scenarios, the effects differ in magnitude depending on rates of adoption and on whether large farms or small farms are the focus of technology adoption efforts. These differential effects will be further explored below in a discussion of more disaggregated results.

4.1.2. Temporally-aggregated Results for Individual Farm Categories

The first important outcome of the disaggregated analysis is that technology adoption increases the average NFOI of adopting farms and generally decreases NFOI for all non-adopting farms when compared with the Baseline (Table 13). Thus, broad adoption of technologies focused on genetic improvements and strategic feeding would improve the individual profitability of farms despite the likely effect of lower milk prices but have a negative impact on non-adopters through price reduction. Therefore, the aggregated benefits of technology adoption would depend not only on the rate of adoption but also on the fraction of adopters in each farm-size category. For example, in the previous section the aggregated analysis indicates that in all scenarios of small farms adopting (SS, SM, and SF) the overall average NFOI is always lower than the *Baseline*, however, the disaggregated interpretation indicates that the net benefits (measured by the weighted average of NFOI) are lower for the larger farms (non-adopters) and higher for small farms even with the portion of non-adopters presenting lower profitability.

Table 13 - Net Farm Operating Income (R\$/farm/month) for each farm-size category for the Baseline and six scenarios of technology improvement, average from January 2006 to December 2016.

| Category (R\$/farm/month) | Baseline | SS | SM | SF | LS | LM | LF |
|-------------------------------------|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|
| <50 L/day | | | | | | | |
| Non-adopters | -2 | -24 | -13 | 48 | -24 | -69 | -85 |
| Adopters | - | 346 | 257 | 236 | - | - | - |
| Weighted average ¹ | - | 70 | 175 | 195 | -24 | -69 | -85 |
| 51-200 L/day | | | | | | | |
| Non-adopters | 144 | 48 | 13 | 132 | 56 | -113 | -171 |
| Adopters | - | 1,094 | 734 | 655 | - | - | - |
| Weighted average | - | 334 | 553 | 573 | 56 | -113 | -171 |
| 201-500 L/day | | | | | | | |
| Non-adopters | 1,634 | 1,250 | 745 | 637 | 1,306 | 774 | 757 |
| Adopters | - | - | - | - | 6,779 | 5,094 | 4,424 |
| Weighted average | - | 1,250 | 745 | 637 | 2,811 | 4,081 | 3,968 |
| 501-1000 L/day | | | | | | | |
| Non-adopters | 5,542 | 4,460 | 2,963 | 2,640 | 4,595 | 2,862 | 2,366 |
| Adopters | - | - | - | - | 16,948 | 13,320 | 11,910 |
| Weighted average | - | 4,460 | 2,963 | 2,640 | 8,102 | 11,123 | 10,965 |
| >1000 L/day | | | | | | | |
| Non-adopters | 19,729 | 16,364 | 11,445 | 10,355 | 16,768 | 11,186 | 9,339 |
| Adopters | - | - | - | - | 49,884 | 39,773 | 35,946 |
| Weighted average | - | 16,364 | 11,445 | 10,355 | 26,293 | 34,049 | 33,549 |

1 – Weighted by the farm proportions using current and improved technologies.

The one exception to the pattern of lower profitability for non-adopting farms is for farms with <50 liters per day in the SF scenario. For these non-adopting farms, average NFOI is higher than in the *Baseline*. This effect arises due to the interaction of price evolution in the Baseline and farm-level decision making in response to profitability changes over time with adoption. In the Baseline, NFOI income becomes consistently negative for farms with < 50 liters per day after January of 2014 (Figure 12a). With adoption by other small farms, non-adopting farms with < 50 liters per day are less profitable than in the Baseline through January of 2014 of the simulation and reduce their cow numbers from an average herd size of 11 cows in response to this lower profitability. The reduction in cow numbers results in lower revenues, but also lower costs, resulting in a smaller negative value of NFOI for these farms after January of 2014 (Figure 12b and 12c). Farms with <50 liters per day thus experience much smaller losses after January of 2014 than farms of this size do in the Baseline scenario, which results in a slightly larger average NFOI. If profitability behavior is assessed by the median value instead the mean we find that NFOI is reduced for all non-adopters compared with the Baseline, indicating that the majority of months have lower NFOI for farms producing < 50 liters per day over this time frame. For the category of non-adopters producing 51-200 liters per day we observed reductions in NFOI with an increased rate of adoption from the SS to SM scenarios, but an increase to nearly the Baseline value for the SF scenario. This pattern differs from what might be expected and what is observed on the other size categories and arises for reasons similar to those that explain the patterns of NFOI for the smallest farms. To better explain these outcomes, NFOI and other related variables in different time frames (short- vs. long-term) of the simulation are presented in the next section as temporally-disaggregated results for individual farm categories.

Figure 12 - Net Farm Operation Income (a), Operational Effective Cost (b) and Total Revenue (c) of non-adopting farms for Baseline and scenario of small farms adopting technology at fast rate (SF), January 2006 to December 2016.

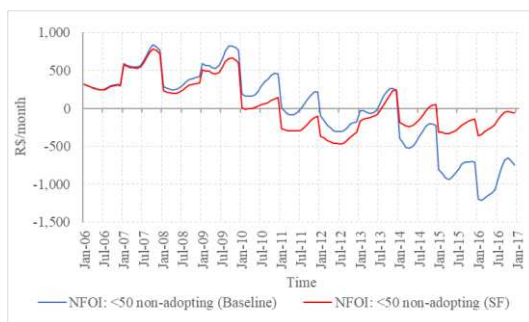


Figure 12a – Net Farm Operating Income on Baseline and SF scenario

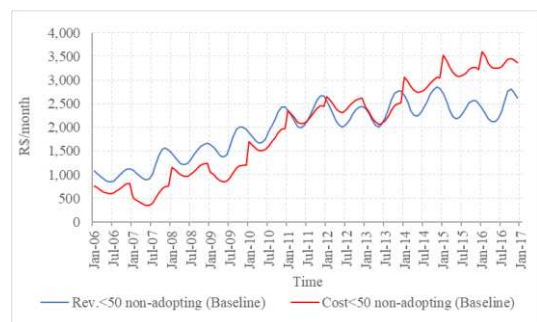


Figure 12b – Total Revenue and Effective Operational Cost on Baseline.

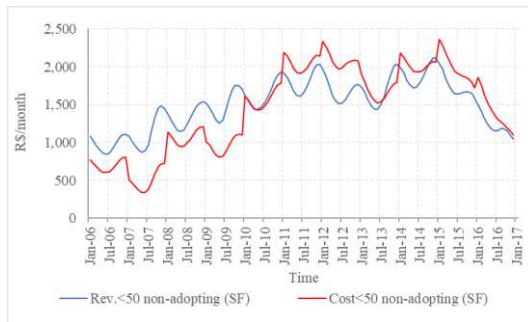


Figure 12c – Total Revenue and Effective Operational Cost on SF scenario.

Adoption by a subset of farms tends to reduce incomes for non-adopters and the major negative impacts tend to be for (non-adopting) small farms in the scenarios where large farms adopt technology. This is a relevant outcome that can explain evidences of milk production concentration by larger farms over time and the likely exit of smaller farms. Due to limited updated official data we assume the total number of farms constant over time. However, our model indicates a significant reduction of herd size and milk production of non-adopting farms (e.g., the average herd size decreases from 20 to 6 cows for the smallest farms by the end of the simulation, Table 15) and suggests that some farms would operate with unit revenues below their variable cost – the economic decision point for stopping production.

Percentage increases in NFOI for adopters tend to be smaller and percentage decreases for non-adopters tend to be larger when technology is adopted more quickly, whether by small or large farms (Table 14). The more rapid adoption of technology means that milk production increases more quickly, and farm milk price decrease faster and to a larger extent. Thus, the fastest rates of adoption tend to reduce the positive impacts on NFOI due to faster milk production growth and lower prices suggesting the possibility of an optimized rate of adoption that would maximize the aggregated NFOI for all farms. It would be interesting from the point of view of farmers (at least for adopters) but could imply in smaller benefits to consumers.

Table 14 - Percentage difference from the Baseline for Average Monthly Net Farm Operating Income for each farm-size category and six scenarios of technology improvement, average from January 2006 to December 2016.

| Category (unit) | Baseline (R\$/farm/month) | SS (%) | SM (%) | SF (%) | LS (%) | LM (%) | LF (%) |
|-------------------------------|-------------------------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| <50 L/day | | | | | | | |
| Non-adopters | -2 | -1,027 | -502 | 2,321 | -990 | -3,075 | -3,829 |
| Adopters | - | 16,136 | 12,011 | 11,049 | - | - | - |
| Weighted average ¹ | - | 3,325 | 8,196 | 9,113 | -990 | -3,075 | -3,829 |
| 51-200 L/day | | | | | | | |
| Non-adopters | 144 | -67 | -91 | -8 | -61 | -179 | -219 |
| Adopters | - | 660 | 410 | 355 | - | - | - |
| Weighted average | - | 132 | 284 | 298 | -61 | -179 | -219 |
| 201-500 L/day | | | | | | | |
| Non-adopters | 1,634 | -24 | -54 | -61 | -20 | -53 | -54 |
| Adopters | - | - | - | - | 315 | 212 | 171 |
| Weighted average | - | -24 | -54 | -61 | 72 | 150 | 143 |
| 501-1000 L/day | | | | | | | |
| Non-adopters | 5,542 | -20 | -47 | -52 | -17 | -48 | -57 |
| Adopters | - | - | - | - | 206 | 140 | 115 |
| Weighted average | - | -20 | -47 | -52 | 46 | 101 | 98 |
| >1000 L/day | | | | | | | |
| Non-adopters | 19,729 | -17 | -42 | -48 | -15 | -43 | -53 |
| Adopters | - | - | - | - | 153 | 102 | 82 |
| Weighted average | - | -17 | -42 | -48 | 33 | 73 | 70 |

Adoption of new technology influences NFOI in part through changes in milk per cow but also through changes in cows owned per farm. The number of cows per farm (and therefore, the total number of cows) at the end of the simulation by farm size category is reduced for non-adopting farms and increased for adopters in all scenarios and sizes (Table 15 and 16).

However, differences in the rate of adoption affect cow numbers differently across scenarios and for different adoption statuses. For non-adopters of any size, an increase in the rate of adoption results in a larger reduction in cows per farm, and this relationship also holds for adopting farms producing less than 500 liters per day. For adopting farms producing more than 500 liters per day, a faster adoption rate increases herd sizes at the end of the simulation. Cow numbers are determined by decisions based on NFOI, and this non-linear effect is observed because the new technologies increase profitability to a larger extent for large farms even when milk prices are reduced more by rapid adoption and adoption by large farms. The analysis accounts for changes in the exogenous initial unit operational costs including feed and genetic improvements, which are reduced more

for these technology changes on large farms (-16%) than small farms (-8%), based on Appendix D.

The assessment of cow numbers supports the hypothesis that the disaggregated analysis is important to understand aggregated behaviors. The net balance between adopters vs. non-adopters and across the size categories in each scenario of adoption rate helps to understand previously-discussed outcomes (e.g., Table 11). For example, the observed cow number reduction in the SS, SM and SF scenarios is because the reduction of cows of non-adopting farms more than offsets the increasing cow numbers for adopting farms. For the scenarios LS, LM and LF, the observed increase of cow numbers at the aggregated level is due the higher magnitude of the increase of adopters in relation to the decreasing of non-adopters.

Table 15 - Number of cows per farm for each farm-size category for the Baseline, and six scenarios with technology improvement, final simulation values in December 2016.

| Category | Baseline | SS | SM | SF | LS | LM | LF |
|-----------------------|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|
| <50 L/day | | | | | | | |
| Non-adopters | 20 | 18 | 12 | 6 | 19 | 17 | 16 |
| Adopters | | 24 | 22 | 22 | - | - | - |
| Weighted Average | | 21 | 22 | 22 | 19 | 17 | 16 |
| 51-200 L/day | | | | | | | |
| Non-adopters | 52 | 48 | 33 | 18 | 50 | 43 | 41 |
| Adopters | | 62 | 55 | 54 | - | - | - |
| Average | | 54 | 54 | 54 | 50 | 43 | 41 |
| 201-500 L/day | | | | | | | |
| Non-adopters | 130 | 119 | 100 | 96 | 120 | 89 | 57 |
| Adopters | | - | - | - | 226 | 223 | 221 |
| Weighted Average | | 119 | 100 | 96 | 164 | 215 | 220 |
| 501-1000 L/day | | | | | | | |
| Non-adopters | 281 | 256 | 211 | 200 | 259 | 206 | 164 |
| Adopters | | - | - | - | 445 | 469 | 480 |
| Weighted Average | | 256 | 211 | 200 | 335 | 453 | 477 |
| >1000 L/day | | | | | | | |
| Non-adopters | 697 | 639 | 522 | 496 | 649 | 517 | 432 |
| Adopters | | - | - | - | 1,054 | 1,119 | 1,145 |
| Weighted Average | | 639 | 522 | 496 | 815 | 1,083 | 1,138 |

Table 16 - Percentage difference from the Baseline for the number of cows for each farm-size category and the six scenarios of technology improvement, final simulation values in December 2016.

| Category | Baseline (cows) | SS (%) | SM (%) | SF (%) | LS (%) | LM (%) | LF (%) |
|-----------------------|----------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| <50 L/day | | | | | | | |
| Non-adopters | 20 | -7.9 | -37.8 | -70.1 | -3.5 | -13.1 | -17.7 |
| Adopters | | 21.8 | 12.8 | 12.4 | - | - | - |
| Weighted Average | | 4.2 | 9.9 | 12 | -3.5 | -13.1 | -17.7 |
| 51-200 L/day | | | | | | | |
| Non-adopters | 52 | -8.5 | -37.5 | -65.7 | -4.5 | -16.6 | -22.2 |
| Adopters | | 19.0 | 5.6 | 4.2 | - | - | - |
| Weighted Average | | 2.8 | 3.0 | 3.8 | -4.5 | -16.6 | -22.2 |
| 201-500 L/day | | | | | | | |
| Non-adopters | 130 | -8.2 | -22.7 | -26.0 | -7.4 | -31.1 | -56.1 |
| Adopters | | - | - | - | 74.4 | 72.2 | 70.8 |
| Weighted Average | | -8.2 | -22.7 | -26.0 | 26.1 | 66.0 | 69.5 |
| 501-1000 L/day | | | | | | | |
| Non-adopters | 281 | -8.8 | -25.1 | -28.7 | -7.8 | -26.9 | -41.5 |
| Adopters | | - | - | - | 58.5 | 66.8 | 70.8 |
| Weighted Average | | -8.8 | -25.1 | -28.7 | 19.4 | 61.2 | 69.6 |
| >1000 L/day | | | | | | | |
| Non-adopters | 697 | -8.3 | -25.0 | -28.7 | -6.8 | -25.8 | -38.0 |
| Adopters | | - | - | - | 51.3 | 60.6 | 64.4 |
| Weighted Average | | -8.3 | -25.0 | -28.7 | 17.0 | 55.4 | 63.4 |

Technology adoption generally results in less NFOI variation over time, although it does increase variation for larger adopting farms (Table 17). By definition, the observed NFOI variations arise from variations in both farm income and costs. Income includes the milk price times milk production per month plus animal sales. Variation in animal sales has a small impact on NFOI. Costs are directly related to cow numbers and milk yield. For instance, non-adopter farms with up to 50 liters per day in scenario SF reduce their final cow numbers by 70% (Table 16) and consequently their operational effective cost resulting in a smaller deviation from the historical average cost when compared with the Baseline (Figure 13a). Adopters over 1,000 liters per day increase the cow numbers in 64% enlarging the deviation from the historical average cost, increasing the NFOI variation (Figure 13b). Results for milk production follow the same pattern when technology is adopted, creating a larger dispersion around the historic average especially in the late period of the simulation. In the next section we assess the most relevant behavior over time that affects the farm profitability.

Table 17 - Standard deviation of the Net Farm Operating Income for each farm-size category for the Baseline, and six scenarios of technology improvement, January 2006 to December 2016*.

| Category | Baseline | SS | SM | SF | LS | LM | LF |
|--------------------------|----------|-------|-------|-------|--------|--------|--------|
| <50 Liters/day | | | | | | | |
| Non-adopters | 527 | 511 | 414 | 336 | 534 | 524 | 516 |
| Adopters | | 492 | 456 | 438 | - | - | - |
| Weighted average | | 476 | 416 | 410 | 534 | 524 | 516 |
| 51-200 L/day | | | | | | | |
| Non-adopters | 1,260 | 1,225 | 990 | 804 | 1,290 | 1,263 | 1,239 |
| Adopters | | 1,082 | 995 | 943 | - | - | - |
| Weighted average | | 1,095 | 929 | 898 | 1,290 | 1,263 | 1,239 |
| 201-500 L/day | | | | | | | |
| Non-adopters | 2,459 | 2,425 | 2,166 | 2,049 | 2,552 | 2,396 | 2,084 |
| Adopters | | - | - | - | 3,115 | 3,037 | 2,852 |
| Weighted average | | 2,425 | 2,166 | 2,049 | 2,185 | 2,842 | 2,793 |
| 501-1000 L/day | | | | | | | |
| Non-adopters | 4,294 | 4,147 | 3,680 | 3,443 | 4,439 | 4,396 | 4,105 |
| Adopters | | - | - | - | 7,585 | 6,760 | 6,262 |
| Weighted average | | 4,147 | 3,680 | 3,443 | 4,429 | 6,628 | 6,453 |
| >1000 L/day | | | | | | | |
| Non-adopters | 10,557 | 9,453 | 8,324 | 7,799 | 10,057 | 9,682 | 9,108 |
| Adopters | | - | - | - | 23,557 | 20,035 | 18,531 |
| Weighted average | | 9,453 | 8,324 | 7,799 | 13,055 | 19,906 | 19,328 |

* NFOI variation is measured by the standard deviation because the coefficient of variation becomes problematic when the data are both positive and negative (Kvålseth, 2017).

Figure 13 - Operational Effective Cost of selected farm categories and scenarios compared with historical average.

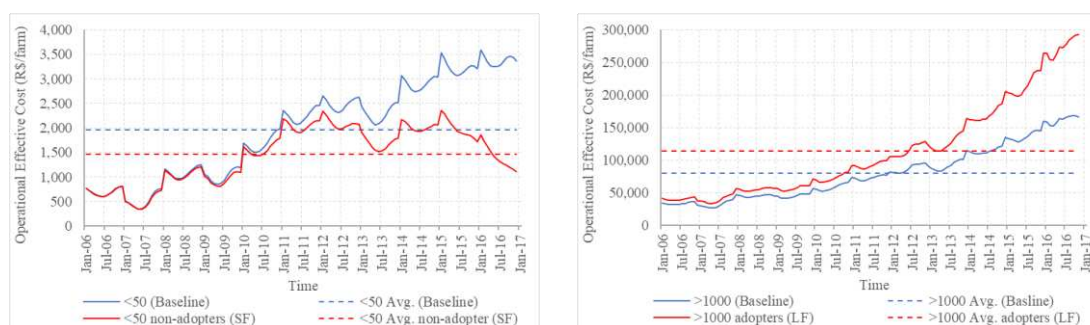


Figure 13a – Operational Effective Cost of non-adopters <50 liters per day farms in SF scenario and Baseline.

Figure 13b – Operational Effective Cost of adopters >1000 liters per day farms in LF scenario and Baseline.

Technology adoption results in lower NFOI variation for both adopting and non-adopting farms in the scenarios which small farms adopt. Despite the significant decrease

of cow numbers that would result in higher NFOI variation for small non-adopters through production costs, its effect is offset by the more stable total income via increasing prices (but lower compared with Baseline) and decreasing milk production. For small adopters of <50 liters/day the coefficient variation of cow numbers and milk production are lower (-47% and -30% respectively) when compared with the Baseline, indicating a lower standard deviation for NFOI. Still, the costs and the total revenue variation are slightly higher (+10 and +17% respectively) resulting in a relative higher NFOI variation when compared with non-adopters. Same pattern is observed for small farms of 51-200 liters per day.

Non-adopter large farms in the scenarios of small farms adopting technology also experience lower NFOI variation. In SF scenario, the coefficient variation of cow numbers decreases 32% and 52% for the categories of 501-1000 and >1000 liters per day, respectively, resulting in a small variation on costs and milk production over time. The farms producing 201-500 liters per day experience a higher variation of cow numbers compared with the Baseline (+96%) however it is not enough to offset the effect of the more stable milk production and total revenue. Similar behavior is observed in SS and SM scenarios.

In the scenarios which large farms adopt technology (LS, LM, and LF), the NFOI variation is larger for adopters due to the increasing number of cows, milk production and consequently costs and revenue in relation to the historical average. In the same scenarios, the large non-adopters would experience changes in NFOI variation between +4% and -15% (Table 18). For farms of categories where NFOI variation is lower, the explanation relies on the reduction of cow numbers that results in a smaller increase in costs compared with the Baseline; the increasing milk price effect is offset by the lower milk production, resulting in a less variable revenue with smaller deviation from the average. For categories with higher NFOI variation (such as 201-500 and 501-1000 in LS, and 501-1000 in LM) the observed behavior of cow numbers, milk production, and operational effective costs are very similar with the Baseline and the increasing deviation is likely due to the complex behavior over time of the NFOI series. NFOI variation is roughly the same as in the Baseline for small farm non-adopters and the small differences are also related with the dynamics behavior.

The variation in NFOI is generally higher for adopters than for non-adopters because of the positive effect of technology adoption on herd, milk production, and costs

(increasing) for the former, and the reduction on cow numbers and costs increasing more slowly than milk production for the latter.

More rapid technology adoption tends to reduce the NFOI variation for both adopters and non-adopters (Table 18). For adopters, the smaller NFOI variation observed for fastest rates reflects the smaller increase in the NFOI value as discussed in Table 14 – fastest rates of adoption tend to reduce the positive impacts on NFOI due to faster milk production growth and lower prices. For non-adopters, the reduction of the NFOI variation is associated with the slower increasing rate of costs and the decreasing milk production due to the effects of the herd dynamics (cow numbers reduction).

Table 18 - Percentage difference from the Baseline for the Standard deviation of the Net Farm Operating Income for each farm-size category, and six scenarios of technology improvement, January 2006 to December 2016.

| Category | Baseline | SS | SM | SF | LS | LM | LF |
|--------------------------|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|
| <50 Liters/day | | | | | | | |
| Non-adopters | 527 | -3.0 | -21.4 | -36.3 | 1.3 | -0.5 | -2.0 |
| Adopters | | -7 | -13 | -17 | - | - | - |
| Weighted average | | -9.7 | -21.1 | -22.2 | 1.3 | -0.5 | -2.0 |
| 51-200 L/day | | | | | | | |
| Non-adopters | 1,260 | -2.8 | -21.5 | -36.2 | 2.4 | 0.2 | -1.7 |
| Adopters | | -14 | -21 | -25 | - | - | - |
| Weighted average | | -13.1 | -26.3 | -28.7 | 2.4 | 0.2 | -1.7 |
| 201-500 L/day | | | | | | | |
| Non-adopters | 2,459 | -1.4 | -11.9 | -16.7 | 3.8 | -2.6 | -15.3 |
| Adopters | | - | - | - | 27 | 23 | 16 |
| Weighted average | | -1.4 | -11.9 | -16.7 | -11.1 | 15.6 | 13.6 |
| 501-1000 L/day | | | | | | | |
| Non-adopters | 4,294 | -3.4 | -14.3 | -19.8 | 3.4 | 2.4 | -4.4 |
| Adopters | | - | - | - | 77 | 57 | 46 |
| Weighted average | | -3.4 | -14.3 | -19.8 | 3.1 | 54.3 | 50.3 |
| >1000 L/day | | | | | | | |
| Non-adopters | 10,557 | -10.5 | -21.2 | -26.1 | -4.7 | -8.3 | -13.7 |
| Adopters | | - | - | - | 123 | 90 | 76 |
| Weighted average | | -10.5 | -21.2 | -26.1 | 23.7 | 88.6 | 83.1 |

The risk of negative NFOI values decreases with increasing farm size for all simulated scenarios (Baseline value) due to the economies of scale in milk production. The larger farms have the average unit operations costs 34% lower than the smaller farms.

The frequency of negative NFOI values increases for non-adopters and markedly decreases when technology is adopted in all scenarios and size categories (Table 19). This is a positive aspect of technology adoption related to the increase of the NFOI value. Even

with more variation over time experienced by large adopter farms, the variation occurs in a higher average level, more often preventing negative NFOI values. The frequency of negative NFOI is reduced for small adopting farms but remains higher than that for large adopting farms.

Table 19 - Proportion of months with negative NFOI values for each farm-size category of Baseline and six scenarios of technology improvement, January 2006 to December 2016.

| Category | Baseline | SS | SM | SF | LS | LM | LF |
|--------------------------|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|
| <50 Liters/day | | | | | | | |
| Non-adopters | 45 | 47 | 51 | 51 | 46 | 51 | 52 |
| Adopters | | 20 | 28 | 28 | - | - | - |
| Weighted average | | 39 | 30 | 29 | 46 | 51 | 52 |
| 51-200 L/day | | | | | | | |
| Non-adopters | 36 | 42 | 50 | 48 | 39 | 48 | 52 |
| Adopters | | 15 | 23 | 25 | - | - | - |
| Weighted average | | 31 | 25 | 27 | 39 | 48 | 52 |
| 201-500 L/day | | | | | | | |
| Non-adopters | 18 | 23 | 35 | 38 | 23 | 33 | 38 |
| Adopters | | - | - | - | 2 | 5 | 6 |
| Weighted average | | 23 | 35 | 38 | 8 | 5 | 6 |
| 501-1000 L/day | | | | | | | |
| Non-adopters | 10 | 13 | 23 | 23 | 14 | 24 | 26 |
| Adopters | | - | - | - | 0 | 1 | 2 |
| Weighted average | | 13 | 23 | 23 | 4 | 2 | 2 |
| >1000 L/day | | | | | | | |
| Non-adopters | 2 | 5 | 9 | 9 | 5 | 10 | 14 |
| Adopters | | - | - | - | 0 | 0 | 0 |
| Weighted average | | 5 | 9 | 9 | 0 | 0 | 0 |

Different patterns of technology adoption would affect the structure of Brazil's dairy sector and the net income distribution. In the Baseline the proportion of milk production of small farms (<200 liters/day) and large farms (>200 liters per day) at the end of the simulation was 25% and 75%, respectively. Technology adoption by small farms (scenarios SS, SM, SF) increases the proportion of milk produced by small farms, to much closer to half of total milk production (43%) under the assumption of the fastest rate of adoption (Figure 14a). On the other hand, if technology is adopted by large farms, the proportion of milk production by large farms would reach nearly 90% for fastest rate of adoption. Thus, our results indicate that the structure of milk production (and therefore the income distribution for dairy farmers) is markedly influenced by which farms adopt and their rate of adoption. The proportion of milk produced by adopters and non-adopters at the end of simulation is similar across each size category given the fixed rate of adoption assumed. In scenarios of slow adoption rate the final proportion produced by

non-adopters and adopters are 40% and 60% respectively, for medium adoption rate the proportions are 2% and 98%, and for the fastest adoption rate all milk produced is provided by the adopters (all values can be seen in Table E3 of the appendix E).

Figure 14 - Distributional effect of technology adoption in milk production and farm income by farm-size category.

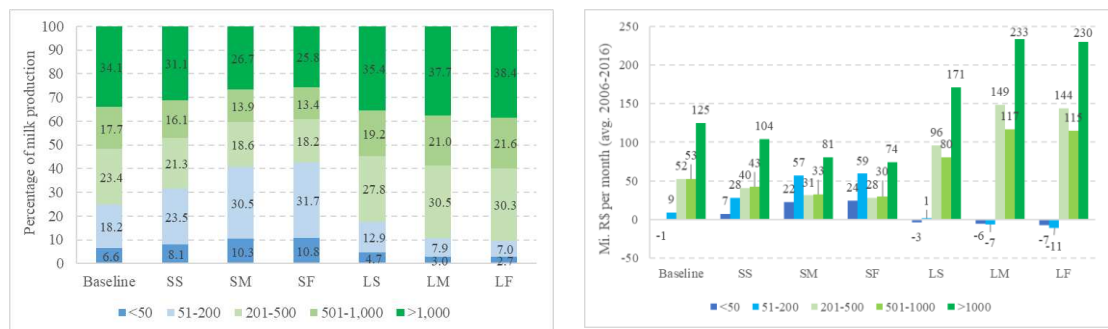


Figure 14a – Percentage of annual milk production for each farm-size category for the Baseline and the six scenarios of adoption rate, in 2016.

Figure 14b – Total Net Farm Operating Income for each farm-size category for the Baseline and the six scenarios of adoption rate, monthly average from January 2006 to December 2016

Technology adoption also affects the distribution of NFOI. When small farms adopt technology (SS, SM, and SF), they experience an impressive increase in the total NFOI and the large farms (non-adopters) experience a less dramatic NFOI reduction. In scenarios LS, LM and LF where large farms adopt the NFOI increase is much larger and besides that imply in negative values for small non-adopter farms (Figure 14b). Thus, our analysis suggests that public or private efforts at dairy sector development through technology adoption will have different impacts depending on which farms are a focus point for efforts to promote technology adoption. Although useful, this information in and of itself does not suggest the preferred strategy for such dairy sector development efforts. This is in part because our scenarios indicate that there are no Pareto superior outcomes in which all farms experience increased NFOI. This implies that some farms would be made better off through technology adoption and others worse off, posing a policy choice about which farms would be in which situation. In addition, relevant costs that would affect outcomes (such as transactions, transportation and transition costs) have not been accounted for in this analysis, and inclusion of the costs could affect which scenarios are preferred. Finally, we have not assessed the programmatic costs or feasibility of achieving the assumed adoption rates, which in reality would affect the observed outcomes.

4.1.3. Temporally-disaggregated Results

This section provides additional discussion of intertemporal simulation results disaggregated by farm size, focusing on farm profitability, herd dynamics and price changes. We focused on key dynamic patterns of the most relevant results that require a dynamic assessment.

Milk prices are on average relative lower (-8.4%) in technology adoption scenarios due to the increase in milk supply, as demonstrated previously in the aggregated results (Table 11). The gap in milk prices between the baseline and scenarios of medium and fast adoption rate is widest in the middle of the simulation period, then closes after 2013 (Figures 15a and 15b). This gap illustrates one dimension of dynamic complexity in Brazil's dairy sector. In the short-run, prices are the most negatively affected, but with completion of the adoption process, dynamic adjustments in cow numbers and demand that play out over longer time frames, the gap is reduced in the long run (although a gap remains). This is similar to the effects noted by Nicholson and Stephenson (2015) where adjustments over time contribute to different short- and long-term outcomes.

Figure 15 - Average milk price for aggregated farm-size categories in the Baseline and the six scenarios of technology adoption, from January 2005 to December 2016.

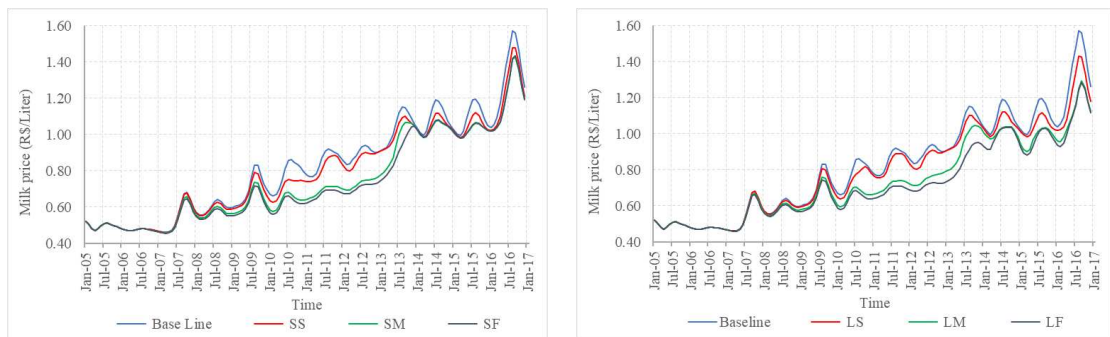


Figure 15a – Scenarios of small farms adopting technology.

Figure 15b – Scenarios of large farms adopting technology.

This observed gap in prices is part of the dynamic adjustment process in the dairy industry but also reflects the relative higher milk production until 2013 compared with the baseline (Figure 16). In scenarios with small farms adopting at the medium and fast rates (SM, SF) the milk production gap is larger until 2013 because of the higher number of small farms increasing production (Figure 16a). After that, the gap is narrowed because of the reduction in cow numbers (Figure 17a), which lowers milk production. When larger farms adopt technology at the faster rates (LM and LF) the milk production results in a smaller difference from Baseline until 2013 and continues increasing after that (Figure

16b). This is also explained by the herd dynamics that are influenced by farm profitability (Figure 17b). In scenarios with slow technology adoption rates the milk production and milk price behaviors are closer to those of the Baseline for both large and small farms.

Figure 16 - Average milk production for aggregated farm-size categories in the Baseline and the six scenarios of technology adoption, from January 2005 to December 2016.

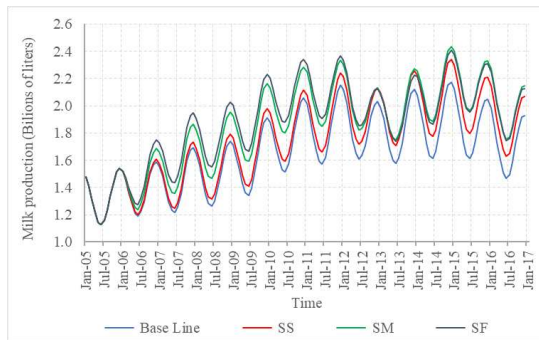


Figure 16a – Scenarios of small farms adopting technology.

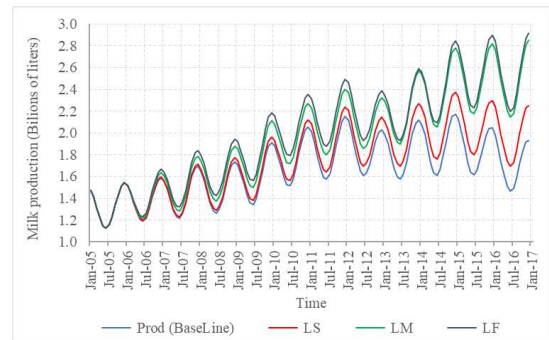


Figure 16b – Scenarios of large farms adopting technology.

In the Baseline there is a decline in cow numbers that begins in 2011 and continues through the end of 2016 (although with some increases), due to profitability impacts. When small farms adopt, this pattern is not changed – the rate of decline in cow numbers increases. When large farms adopt, however, the pattern of fluctuations is similar, but cow numbers increase – as discussed in previous sections of temporally-aggregated outcomes. Profitability is lower and shows negative values more often after 2012 mainly due to exogenous impact of ration price changes. Farmers are assumed to adjust their cow numbers according to the NFOI relative to a reference NFOI obtained by calibration process for each size category. As described on *Methods and Data Description* section, if NFOI is lower than the reference NFOI farmers increase their culling-rate and reduce culling if NOFI is higher than the reference.

Figure 17 - Average cow numbers for aggregated farm-size categories in the Baseline and the six scenarios of technology adoption, from January 2005 to December 2016.

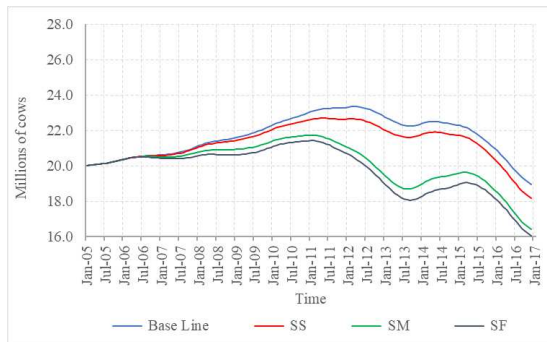


Figure 17a – Scenarios of small farms adopting technology.

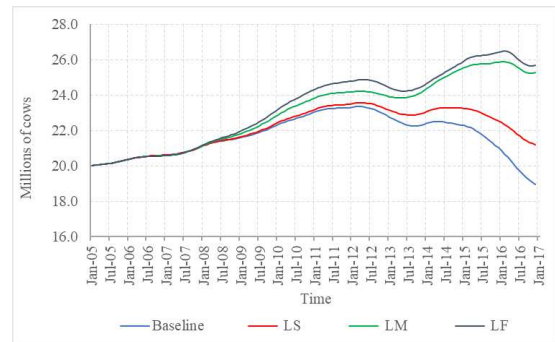


Figure 17b – Scenarios of large farms adopting technology.

All non-adopting farms experience decreased NFOI when compared with the Baseline, as noted in (Table 13), except for the category of <50 liters per day. The temporally disaggregated analysis indicates that the NFOI is lower than the Baseline until late 2013 and then becomes higher for the <50 liters per day category and for 51-200 liters per day (Figure 18a and 18b), however, the resulting average NFOI for the latter is a slightly lower (-8%). These results are also related to the herd composition in these two periods (before and after 2012-13). Reduction in cow numbers result in lower total revenue but also lower costs, resulting in a less negative NFOI towards the end of simulation. This suggests that the negative impacts on NFOI for non-adopters, similar to farm milk prices, exhibit dynamic complexity (worse before better behavior). It is also worth noting that adoption per se does not prevent lower (and negative) NFOI values for adopting farms beginning in 2015. The negative NFOI values occur more frequently later in simulation exactly when one would expect that technology adopters evolved to a better profitability situation (Figure 18). This is due to the increase in production costs (especially the exogenous ration price, which increase more later in the simulation period) and with the long-term adjustment of milk price – dynamic complexity due the presence of delays.

Figuer 18 – Figure 18 - Net Farm Operating Income for each farm-size category in the scenarios of fast technology adoption, from January 2006 to December 2016*.

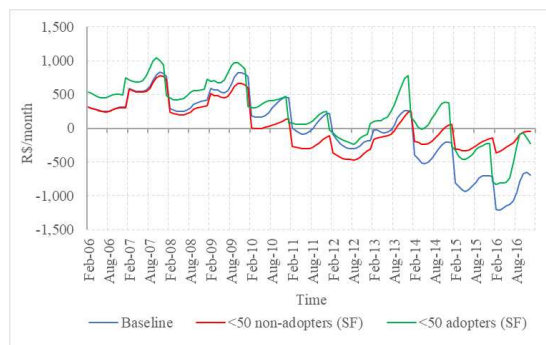


Figure 18a – Farms up to 50 liters per day.

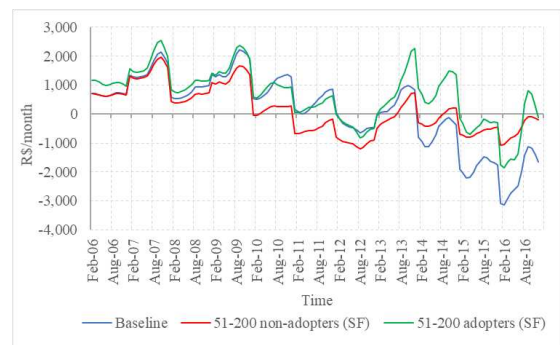


Figure 18b – Farms of 51-200 liters per day.

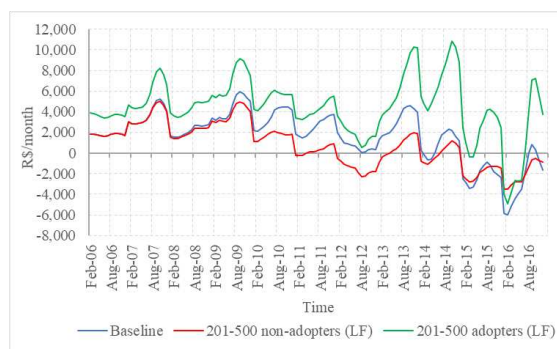


Figure 18c – Farms of 201-500 liters per day.

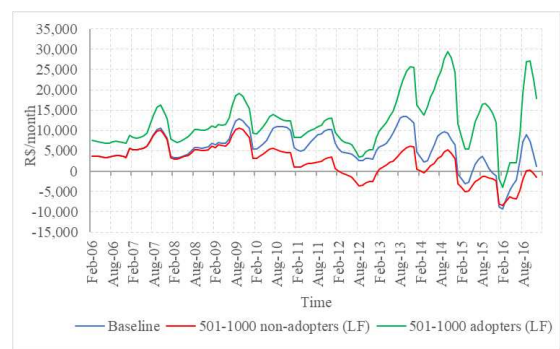


Figure 18d – Farms of 501-1,000 liters per day.

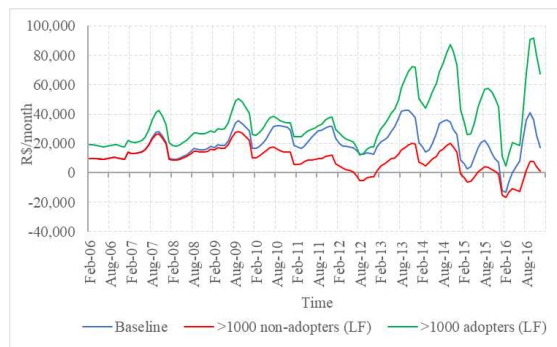


Figure 18e – Farms of above 1,000 liters per day.

*Vertical axes in different scales.

The increase in adoption rate from slow to fast tends to lower the increase of NFOI for adopting farms due to faster milk production growth and lower prices. However, for small farms, in the first 7 years after technology implementation (three-quarters of the simulation period), the slower rates of adoption result in a larger NFOI than the other scenarios but then NFOI becomes slightly lower. This effect arises due to delays in the system – higher profitability than for faster growth scenarios during the initial years of

the simulation means that farms retain more cows and when costs increase in 2014 this implies a more negative NFOI (Figure 19).

Figure 19 - NFOI of small adopters across the three scenarios of technology adoption rate, from January 2006 to December 2016.

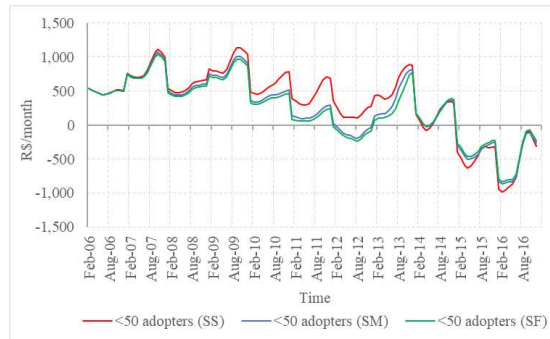


Figure 19a – Small adopter farms of <50 liters per day in scenario of small farms adopting.

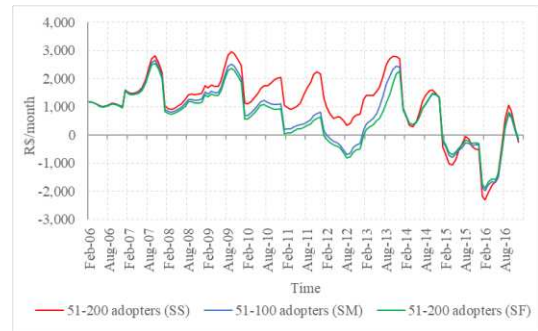


Figure 19b – Small adopter farms of 51-200 liters per day in scenario of small farms adopting.

Because technology adoption also affects culling rates, it influences prices for culled animals, which in turn affects NFOI. When small farms adopt technology, the cull cow price is lower than the Baseline in the first three-quarters of the simulation and then becomes higher (Figure 20a). This effect mirrors that of milk prices and NFOI, with different behaviors in the short and long term. When large farms adopt the cull cow price is initially higher (up to half of the simulation period) and then remains below the Baseline after August 2010 (Figure 20b). The cull price responds inversely the availability of cull cows (Figure 20c and 20d). This is a complex behavior of short- and long-term differences determined by the feedback process with delays. Cow cull price is updated endogenously by the supply changes on the cow numbers send to culling (cow cull rate). The culling rate is a farmer's decision based on farm profitability (NFOI value). Value of livestock sales is a secondary component of dairy farming revenues and consequently affects the NFOI behavior. Thus, cow cull rate is both determined by and determines variations on NFOI.

Figure 20 - Cull cow price and cull rate in the six scenarios of technology adoption rate, from January 2006 to December 2016.

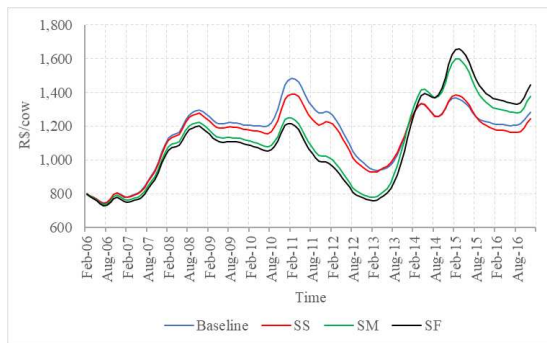


Figure 20a – Cull cow price for small farms adopting technology.

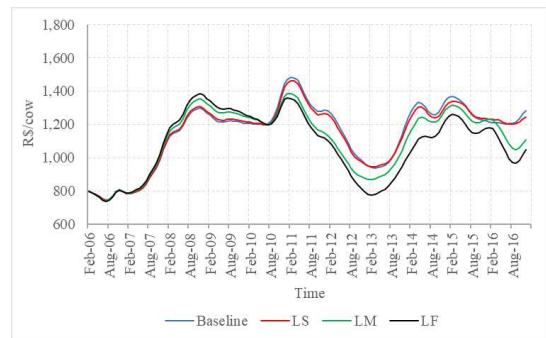


Figure 20b – Cull cow price for large farms adopting technology.

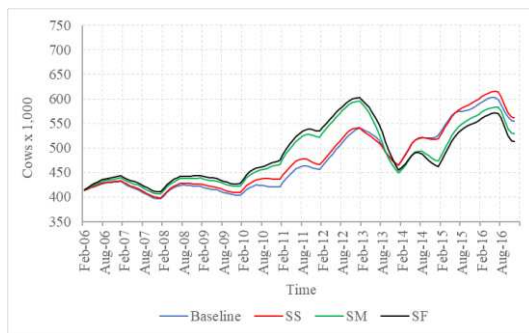


Figure 20c – Cull rate for small farms adopting technology.

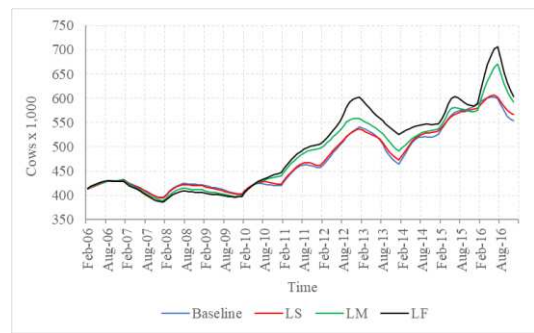


Figure 20d - Cull rate for large farms adopting technology.

Milk supply dynamics influence the pattern of demand for dairy products, primarily for fluid milk but also for other dairy products. The larger impact on fluid demand is due to the longer adjustment time required for demand of non-fluid products and for processors to adjust capacity utilization. Fluid milk also is the main component of the price paid to farmers (Figure 21). Technology adoption results in smaller-amplitude oscillations in fluid consumption over time (Figure 21a and 21b) but only slightly modifies the consumption of storable and soft products (not represented). Demand for balancing products is increased in the middle of simulation period due to the higher inventory levels brought about by larger milk supplies (Figure 21c and 21d). The allocation by priority function (presented in the Methods section) allocates surplus farm milk production to balancing products, lowering their price, and consequently, increasing the consumption.

Figure 21 - Final domestic demand of dairy products in the six scenarios of technology adoption from January 2006 to December 2016.

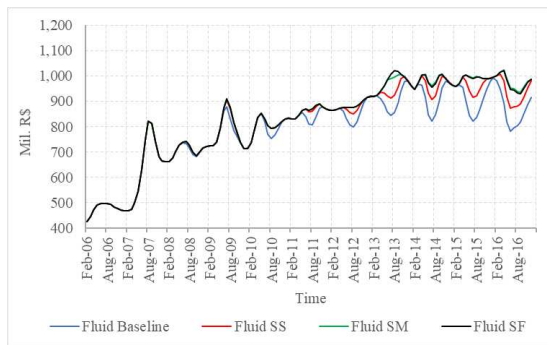


Figure 21a – Fluid milk consumption in scenarios of technology adoption by small farms.

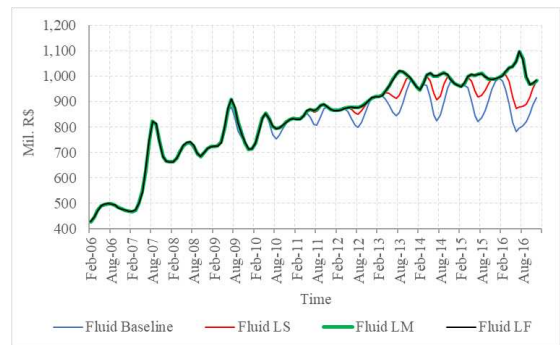


Figure 21b – Fluid milk consumption in scenarios of technology adoption by large farms.

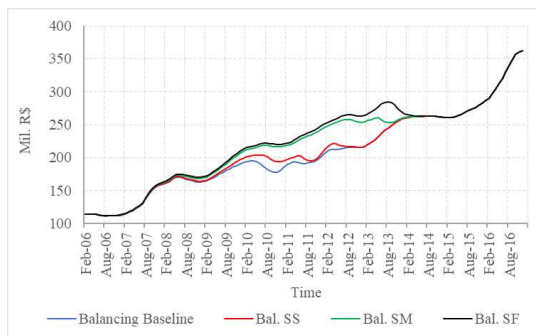


Figure 21c – Balancing products consumption in scenarios of technology adoption by small farms.

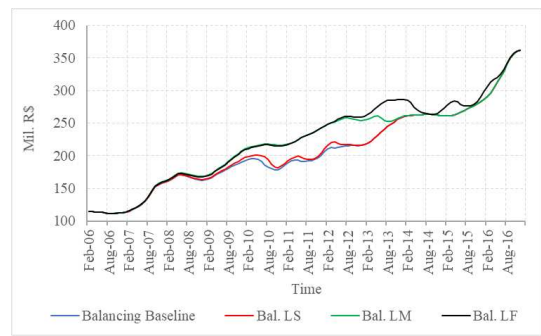


Figure 21d – Balancing products consumption in scenarios of technology adoption by large farms.

4.2. Discussion

Studies on the diffusion of innovation in agriculture are often focused on the potential benefits of technology adoption at the individual farm level, particularly those related to enhanced productivity and production increases for adopters, or on differences in characteristics of adopting and non-adopting farms. This study differs from many previous ones in that it assumes rates of technology adoption for productivity-enhancing (and cost-decreasing) practices, then focuses on the market and distributional impacts at the production sector. We assume that technology is not adopted instantaneously by all farmers and different rates of adoption may result in a fraction of non-adopter farmers, which is consistent with general diffusion theory and particularly in studies of the dairy sector. According to Khanal et al. (2010), dairy researchers often focus on determining the effect of a single technology or management practice on profitability or productivity and it is clear from this analysis that singling out a particular innovation may do not

accurately estimate its potential benefits due potential interactions with other practices often concomitantly adopted. This is the same argument of Feder et al. (1985) that in many cases several innovations which have various degrees of complementarity are introduced simultaneously. It follows that adoption decisions for various innovations often are interrelated. In this sense, our analysis didn't focus on isolated particular technology assuming that adopters of a particular technology are also the adopters of other technologies and management practices. Rather, we assumed the adoption of a technological package that comprised coordination of genetic gains and complementary feeding strategies which also included adjustment of the cost structure for each farm size.

Consistent with previous literature and our expectations, we found that technology adoption results in larger average total production at the aggregated level and lower milk prices to farmers. This is qualitatively the same result obtained for analysis of dairy technologies by Zepeda et al. (1991) for the adoption of the bovine somatotropin (bST - a growth hormone to increase milk yield) and the use of sexed semen in US dairy industry highlighted by De Vries et al. (2008). Zepeda et al found that adoption of bST would lower farm prices from -2.8% to -8.7% due to a production increase of 3.8 to 11.6% given two assumed adoption rates and two physiological response scenarios. For bST adoption, the aggregated analysis indicate that use of productivity-enhancing technologies would slightly increase aggregated net farm income. This is also true in the case of our analysis of complementary adoption of improved genetics and feeding on Brazilian dairy farms. However, the aggregated analysis can mask important disaggregated effects. Our disaggregated analysis indicated that higher overall production emerges from the net outcomes obtained by adopters versus non-adopters and this condition holds for other aggregated key variables like net farm income and herd size. Thus, the possibility exists for negative effects of technology adoption on farm profitability because lower average prices more than offset the revenue gains from increased milk production by technology adopters – in our case, this is observed in the scenarios which small farms adopt technology. Despite the consumer preferences expressed more recently for milk produced without bST, the adoption of bST would have increased the retail volume sold and consumers would be benefited by paying less for the fluid milk. This impact on consumer welfare is the same outcome found by Carvalho (2015) when technology adoption in Brazil shifts the supply curve of dairy products in a partial equilibrium econometric model.

Our analysis also suggests that the supply response induced by technology adoption (and thus both farm-level and aggregated outcomes) can differ among farms

types despite the same assumptions about responsiveness of desired cow numbers to profitability and rates of adoption. That is, we used the same response function (a lookup function based on the ratio of current to reference NFOI, see Equation 58 and Figure A1 in Appendix A) for the effect of expected NFOI on desired herd size for all farms. Thus, the different responsiveness we found is related to both exogenous assumptions and endogenous dynamics. Exogenous assumptions include the different starting relative NFOI values in each farm category and the initial impact of technology at the farm level differs (i.e., different static profitability impacts). In addition, the underlying causal structure (represented by the stock-and-flow structure in the Methods and Data Description section) captured more complex feedback dynamics than most previous econometric models (e.g., Bhattacharya et al., 2016; Bozic et al., 2012; and Chavas and Kraus, 1990).

It was noted earlier that the model contains five farm-size categories comprising differences in genetic composition and feed strategies representing the dairy farming sector in Brazil. We simulate adoption of technology improvement in two sets of farms divided by size (small and large farms) at three different adoption rates – which are assumed the same for all adopting farms. The supply response differs by farm size despite the same assumed rate of adoption, in part because the farm-level economic benefits of adoption differ by size and also due to the initial composition of the industry, which affects the aggregate impacts of adoption through overall milk supply and demand. Souza (2000) also demonstrated that production systems with different technological characteristics – indicated by the herd genetic composition – show distinct response conditions to market stimuli. In Brazil, farms with the Holstein breed had a higher supply elasticity than the Zebu x Holstein crossbreeding and the pure Zebu breed systems respectively. Our model structure is capturing a similar type of effect due to differences in size and technology level that reflect increases in genetic potential for milk production. For instance, when small farms (that by assumption are Zebu breed-based systems) adopt technology at faster rates the milk production increases by 14% on average, whereas larger farms (that are Holstein-based systems) adopt technology at the same rate the milk production increases by 21%.

Adelaja (1991) highlights that economists tend to ignore the effects of price changes on farm population and herd size and the possibility of heterogeneity in short- and long-run output responsiveness of dairy farms. The author estimated a disaggregated measures of supply response demonstrating theoretically and empirically that short and long-term output responsiveness of dairy farms vary with farm size due the size-related

differences in elasticities of yield, herd size, and the number of farms. These differences can arise from differences in capital intensity and specialization, financial ability, and magnitudes of barriers to entry, exit, and crossover. The farm population distribution in terms of adopters or non-adopters and small or larger categories play an important role in our simulations, determining the net-outcome in key variables, for example, the weighted average NFOI of small farms in the scenarios of small farms adopting technology (SS, SM, and SF), Table 13.

Previous models that assessed the herd dynamics based on changes in economic variables are consonant with our model assumptions that herd size is affected by net farm income via culling rate adjustments. For example, Bhattacharya et al (2016) found that one percent change in milk price leads to a greater than one percent increase in the number of milking cows and hence the total milk production in developing countries (BRICs). Bozic et al. (2012) modified the dynamic model of Chavas and Klemme (1986) to investigate the impact of US milk prices and feed costs on culling rate and on the aggregated herd size. They found counterintuitive outcomes contradicting previous models with a declining trend in long-run supply elasticity from 1975 through 2005 highlighting that larger price swings would be needed to quickly equilibrate the market in face of demand shocks. Our temporally disaggregated analysis also indicates the presence dynamic complexity in between supply response and prices. For instance, in the simulation of faster technology adoption rate, the milk price decreases more in the short-term and then becomes more similar to the non-adoption scenario (Baseline) indicating a dynamic adjustment on farm profitability and herd size. This dynamic is similar to the behavior found by Nicholson and Stephenson (2015) where the increased average price results from a short-term increase that more than offset the longer-term decreases. When technology adoption was simulated at different rates by Weersink and Tauer (1990) in selected US regions, prices become generally lower in the early simulation period and then increased, with consequent effects on net income and the value of quasi-fixed assets like cows and labor. Our scenarios demonstrate further details beyond the temporal complexity. Technology adoption and higher profitability of one group, for example, large adopter farms, could result in lower profitability in another group like small non-adopters via market effects. This is in agreement with what Weersink and Tauer determined for contrasting different milk production regions in the US.

Our analysis also allows an assessment of the impact of technology adoption on milk production concentration. When large farms adopt technology, small non-adopters

tend to significantly reduce their herd size below the expected minimum production scale. It was not possible to calculate explicitly the farm exit rate in Brazil, however, reduction in cow numbers and profitability may provide a reasonable proxy for this effect on the dairy industry (Tauer, 1998). Previous works highlight that technology adoption is a major determinant of structural changes especially in dairy farming. According to El-Osta and Morehart (2000) and Quiroga and Bravo-Ureta (1992) technological advances produce larger farms with higher productivity, lower costs but fewer in number. Weersink and Tauer (1991) tried to explain the causality between farm-size in US and profitability using causality tests. Their results only partially support the view that technological change has caused increases in dairy farm size. For them, the direction of causality appears to be more from size to productivity. Changes in productivity and average herd size also appears to be driven by price changes. For System Dynamics models, causality and endogeneity are part of the solution once this is strongly grounded on feedback loops (Sterman, 2000). In this case and aligned with our dynamic hypothesis (Figure 1 in the *Introduction* section), the higher is the technology adoption rate, the higher is the profitability of adopters resulting in larger farms. Consequently, larger adopter farms potentially displace small and non-adopters from their current market share via profitability reduction. In less specific case, Feder et al. (1985) indicate that the early adopters (usually the larger and wealthier farms) can accumulate more wealth and use the differential in the subjective value of land to acquire more land from the laggards. The acquisition of new wealth enables further adoption and thus affects the dynamic pattern of aggregate adoption. Thus, particular attention to changes in landholding patterns and wealth accumulation probably is warranted for Brazil's dairy sector in the case of widespread adoption of new technologies.

5. CONCLUSION

We developed a dynamic model of the Brazilian dairy supply chain and assessed the impact of technology adoption rates on farm-level and market outcomes. Technology adoption at our assumed rates would increase milk production and lower milk and dairy product prices, providing benefits to many adopting farms and to dairy product consumers. Faster technology adoption rates result in lower milk prices and would offset many of the benefits of increased efficiency at the farm level. A more disaggregated analysis indicated that technology adoption increases the farm profitability of adopters but reduces profitability for non-adopters and makes negative Net Farm Operating Income (NFOI) more frequent, especially for small farms. Technology adoption as assumed in our analysis would also imply substantive changes in the dairy production sector of Brazil. Depending on which farms types are assumed to adopt technology, the proportion of milk production and total farm operating income by smaller (< 201 liters per farm per day) and larger (> 200 liters per farm per day) farms would be markedly changed. This is an important outcome for policymakers and is related to the observed exits of small farms and the concentration of milk production on larger and more efficient farms during the past two decades.

Alves et al. (2016) indicated that the proportion of agribusiness income generated by the largest farms can be increased by the promotion of technologies that cannot be adopted by smaller farms. Because we assumed technologies would be adopted by all farm types to allow analysis of farm-level and market impacts, we cannot directly compare our results to theirs. However, our findings complement theirs in two ways. First, we highlighted that the proportion of production and income by small farms can be increased if they are the adopters of technologies that are feasible both technically and financially. Second, non-adopters of technology – whether large or small farms – can experience lower incomes and a smaller production and income shares when other farms adopt. We noted that the underlying causal structure of farm profitability and the herd management decisions are enough to explain the potential market exclusion of non-adopting farms when others decide to improve the productivity of their systems in efficient markets.

Another major result of our analysis is that technology adoption can affect variation in farm profitability, but this differs by farm size and technology adoption scenarios. For small farms, the standard deviation of NFOI is reduced regardless of assumptions about which farms adopt technology at what rate, although the reductions are greater when larger farms are assumed to adopt and for faster adoption. For large farms, the standard deviation of NFOI tends to be reduced when large farms are non-

adopters, and markedly increased when they adopt the technology. These patterns of change arise because variation in NFOI is driven by variation in milk prices, given our assumptions about constant unit costs of production. When small farms adopt technologies, a primary effect is lower milk prices and milk price variation, which lowers the standard deviation for most farms. When large farms adopt, there is an additional profitability effect that results in increased cow numbers, which both contributes to and dominates the impact of more stable milk prices, resulting in increased average income and overall variability. Another measure of financial risks for farms is the proportion of months with negative NFOI values. We find that regardless of the scenario or farm size, adoption decreases the proportion of negative NFOI values and non-adoption increases it. The degree to which these changes in farm-level financial risk have management implications for Brazil's dairy farms could be usefully explored by additional research.

Consistent with much previous work using system dynamics modeling, the presence of feedback processes and delays due to bio-physical factors and economic decision-making result in important dynamic complexity: short- and long-run outcomes differ for many key dairy industry variables. One example is that the price difference between the Baseline simulation and scenarios with technology adoption at medium and fast rates is larger in the middle of the simulation than in the beginning and by the end of the adoption process. Over time, the system adapts to bring prices into closer alignment with the situation without technology adoption. A second example is that the profitability of small non-adopting farms is initially worse when technology is adopted by other farms, but then becomes better than in the Baseline. This “worse before better” outcome is counterintuitive but not unexpected based on system structure.

Finally, our work is broadly consistent with previous literature assessing technology adoption impacts on market variables, which indicates that a substantive proportion of the benefits of farm-level adoption accrue to supply chain entities other than farmers, notably, processors, retailers and consumers. In this sense, we highlighted that agricultural scientists should be aware of the possibility that the broad promotion of their innovations could reduce financial welfare for farmers, even if it benefits retailers and consumers with higher volumes sold, lower and less volatile prices. *Ex ante* impact assessments through dynamic simulation of market outcomes are thus a powerful tool to anticipate welfare effects and can be used more pro-actively in the design and promotion of productivity-enhancing technologies.

6. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

All simulation models are imperfect representations of a more complex reality because these simplify and abstract the system for the purposes of analysis. Limitations are often related to both the model structure and data availability and consistency. Although our model was evaluated in a systematic manner and deemed appropriate for its stated purposes, there are a number of potential modifications that could alter the numerical results if not the basic conclusions of this study. One key issue is the availability of relevant data. A dairy supply chain model requires a good deal of information that in principle should be internally consistent. For example, the demands for products made from farm milk should be roughly consistent with the farm milk used in processing, i.e., there should be a balance of milk components in farm milk and products for the country as a whole. This set of consistent data does not exist for Brazil (and for most countries), and many industry analysts do not appear aware of the fundamental need for mass balance in sector-level analyses. Thus, we were required to merge and combine different official databases and adjust them with specialist opinion to force a consistency. In addition, the wide range of dairy products sold in Brazil were aggregated into only four categories although products with differing characteristics might usefully be represented in separate categories, e.g. *Minas cheese* (fresh cheese), *doce de leite*, *requeijão* and ice-cream. However, as wholesale and retail sectors were not our focus the use of fewer categories is likely to be a reasonable representation of the Brazilian dairy industry and further product disaggregation likely would not affect the basic results of our study.

For much of the farm-level model representation, we used data from Minas Gerais as a proxy for farms throughout Brazil, and aggregated farms by size without consideration of regional differences. Additional detailed data about farm characteristics and responses by region would allow additional insights about potential differences in regional impact, which would undoubtedly be useful to policymakers and researchers working on technology development. Assessment of outcomes for three major regions (south, center-southeast, and northeast) would be an initial extension of our work and can be easily done using the subscript capability in Vensim if sufficient data were available. Accounting for differences in production systems, cultural influences and climate and soil conditions would result in more accurate information for policymakers, as was highlighted by Weersink and Tauer (1990). We considered the number of farms within each size category constant over time and could therefore make only indirect inferences

about the possible exit process based on the simulated significant reduction in average herd size and lower farm profitability. Updated data about the number of dairy farms in Brazil would help to improve the structure and allow the farm exit process endogenously determined, as in Nicholson and Stephenson (2014).

We also simplified the representation of farm milk prices and price formation. The model assumes that the same average price is paid to all Brazilian dairy farms, which is undoubtedly unrealistic. We also assume that milk prices can differ for milk used in different products based on formulas that link dairy product prices to farm milk prices through yields and markups. The inclusion of different prices for different farm categories based on production scale and milk quality would likely result in larger differences between adopters versus non-adopters and larger versus small farms. The Brazilian dairy industry also lacks transparency regarding how raw milk is purchased and utilized by dairy processors and processing sector costs and returns. Further research to understand the process of milk price formation paid to farmers and processing costs and returns would allow for a better representation of behaviors and outcomes for both farms and processing sector. Finally, milk prices tend to vary spatially based on region-specific milk supply, milk demand and transportation costs. Additional representation of these factors could provide a better understanding of regional impacts and better inform sector development policy decisions.

Additional endogenous structures would also be relevant considerations for the next steps of model development. The current model structure uses exogenous historical prices for the ration fed dairy cows. The integration of our dairy sector model with elements of other supply chains such as corn and soybean that are major components of concentrated ration (and thus important to determine milk production costs) would enhance understanding of the underlying causes of input price changes and milk price behavior. We also assume that developments in the dairy sector (expansion or reduction in utilized area) are not affected by changes in the relative profitability of other agricultural activities. There is evidence that the sugar cane policy in Brazil and the Renewable Fuel Standard policy in the U.S. could affect the Brazil's dairy industry (Carvalho et al., 2015). Thus, more detailed representation of other agricultural activities, for example, through an agricultural sector model (Wiborg, 2000) may be relevant for future model development.

Another rather obvious extension of our modeling framework concerns international trade. In discussions of the global dairy industry, Brazil is frequently

mentioned as a potential exporter of dairy products given its large milk production capacity. Our current model assumes exogenous historical imports and exports, which is probably reasonable given the focus on domestic technology adoption and the limited price integration with global dairy product markets (Nicholson and Novakovic, 2017). Formulating a model to make imports and exports endogenous could be undertaken either with a simplified “Rest of World” structure (as in Nicholson and Stephenson 2014) or through the more effort-intensive integration with a more comprehensive model of international dairy markets. Either approach to model extension would provide insights about the drivers of imports and exports and impacts on Brazilian dairy markets. It would also provide prospective insights about opportunities and threats from linkages with global dairy markets that would be of interest to dairy industry stakeholders.

Finally, we assumed the rates of technology adoption were exogenous, which is appropriate for the purpose of assessing farm-level and aggregated impacts but provides few insights about the actual adoption process. Assuming exogenous adoption ignores potential feedback processes relevant to assessment of market outcomes, for example, that lower profitability due to adoption may reduce incentives for future adoption (or even result in dis-adoption). Thus, modeling technology adoption as an endogenous process would be highly relevant. Additional research on factors influencing adoption dynamics would likely be needed before these could be included in an extension of our model, but simplified representations based on the Bass diffusion model (e.g. Mahajan et al., 1990) could provide a conceptual framework and allow assessment of initial hypotheses. Related to technology adoption, we assumed a static and simplified set of biological relationships between farm level crop production and cow productive and reproductive performance. The integration of a more sophisticated biological structure (e.g. crop and cow nutrition simulation models) developed through interdisciplinary efforts could help to assess milk supply response to different nutritional management strategies.

System dynamics models often have been used to provide insights about the causal mechanisms underlying observed behaviors. As such, they have tended to be used to understand the origins of observed behavioral modes rather than for point-specific forecasting (Sterman, 2000). However, with more and updated data it would be possible to use model to assess general patterns for future prices (Kapmeier and Voigt, 2013; Nicholson and Stephenson, 2018) and product demand. Our model framework also provides a strong basis for extensions to explore a wide variety of policy options for Brazil’s dairy sector, not just those related to technology adoption. Industry analysts and

political decision makers would likely have interest in dynamic assessment of the outcomes of governmental programs like Minimum Price Guarantee Policy or Margin Protection Program (MPP) as in the U.S. (Nicholson and Stephenson, 2014a). These extensions illustrate the broad usefulness of investments in dynamic modeling capacity and would have relatively low marginal cost given the current stage of model development.

7. BIBLIOGRAPHY

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APPENDIX - A

Table A 1- List of equations in Milk production stock-flow structure.

| Eq.# | Equations | Units |
|------|---|-------------------------|
| 1 | Farm Milk Price over Feed Cost per Liter [S,T] = Current Farm Milk Price/Feed Cost Per Liter[S,T] | Dmnl |
| 2 | Effect of Feed Prices on Production[S,T] = (Farm Milk Price over Feed Cost per Liter[S,T]/"Reference Milk Price / Feed Price Ratio"[S,T])^"Sensitivity of Milk Per Cow to Milk/Feed Cost"[S,T] | Dmnl |
| 3 | Desired Genetic Potential Expressed[S,T] = Reference Fraction of Potential Expressed[S,T]*Effect of Feed Prices on Production[S,T] | Dmnl |
| 4 | Change in Production Practices[S,T] = (Desired Genetic Potential Expressed[S,T]-Fraction of Genetic Potential Expressed[S,T])/Production Practice Adjustment Time[S,T] | 1/month |
| 5 | Fraction of Genetic Potential Expressed[S,T] = INTEG(Change in Production Practices[S,T], Initial Fraction of Potential Expressed[S,T]) | Dmnl |
| 6 | Actual Milk per Cow per Month[S,T] = IF THEN ELSE(Farm Proportion[S,T] = 0, 0, (Maximum Genetic Potential for Milk Production [S,T]*Fraction of Genetic Potential Expressed[S,T])*(1+Seasonality[S,T])) | L/cow/month |
| 7 | Seasonality[S,T] = Seasonality Amplitude[S,T]*COS(2*3.14159*(Time-Peak Month Yield)/Seasonality Period)*Switch Seasonality | Dmnl |
| 8 | Genetic Gains[S,T] = IF THEN ELSE("Switch Potential Milk per Cow Growth Rate on-off"=0, 0, Maximum Genetic Potential for Milk Production[S,T]*(Potential Milk per Cow Growth Rate[S,T]/Month per year) Liter/(Month*cow)/Month) | Liter/(cow*Month*Month) |
| 9 | Maximum Genetic Potential for Milk Production[S,T] = INTEG(Genetic Gains[S,T], Initial Maximum Potential Milk per Cow[S,T]) | Liter/Month/cow |
| 10 | Initial Maximum Potential Milk per Cow[S,T] = Initial Maximum Potential Milk per Cow per day[S,T]*Days per month | Liter/Month/cow |
| 11 | Milk per Cow per Year[S,T] = Actual Milk per Cow per Month[S,T]*Months per year | Liter/cow/year |
| 12 | Milk per Cow per Day[S,T] = Actual Milk per Cow per Month[S,T]/Days per month | Liter/cow/day |
| 13 | Milk per Cow per Day W.Avg = SUM(Milk per Cow per Day[S!,T!]*Farm Proportion[S!,T!]) | Liter/cow/day |
| 14 | W.Avg Milk per Cow per Month = SUM(Actual Milk per Cow per Month[S!,T!] * Farm Proportion[S!,T!]) Liter/(cow*Month) | Liter/cow/Month |
| 15 | Milk Production = Sum Reference Cows on Farm*"W.Avg Milk per Cow per Month"*Fraction of Formal Production | Liter/Month |
| 16 | Sum Reference Cows on Farm = SUM(Reference Cows on Farms[S!,T!]) | Cows |
| 17 | Total Milk Production on Farm[S,T]= Actual Milk per Cow per Month[S,T] * Reference Cows on Farms[S,T] | Liter/Month |

| | | |
|----|--|------------------|
| 18 | Reference Cows on Farms[S,T] = (Cows[S,T]*Fraction of Formal Production) - (Cows[S,T]*Minimum Fraction of Specialized Milk Cows) | Cows |
| 19 | Formal Milk Production on Farm[S,T] = (Total Milk Production on Farm[S,T] *Fraction of Formal Production) | Liter/Month |
| 20 | Milk Production Per Farm[S,T] = ZIDZ(Formal Milk Production on Farm[S,T],Farms by Category[S,T]) | Liter/Month/farm |
| 21 | Farms by Category[S,T] = INTEG(+Switch Farm Category[S,T], Number of farms by Size Category[S,T]) | Farm |
| 22 | Switch Farm Category[S,Non-adopters] = -Farms by Category[S,Non-adopters] *Change in Proportion[S]/TIME STEP | farm/Month |
| 23 | Switch Farm Category[S,Adopters]= Farms by Category[S,Non-adopters] *Change in Proportion[S]/TIME STEP | farm/Month |
| 24 | Total Farms = SUM(Farms by Category[S!,T!]) | Farm |
| 25 | Farm Proportion[S,T] = Farms by Category[S,T]/Total Farms | Dmnl |
| 26 | Number of farms by Size Category[S,T] = Specialized Farms*Fraction of Farms in Each Category[S,T] | Farm |
| 27 | Specialized Farms = Formal Farms*Minimum Fraction of Specialized Dairy Farm | Farm |
| 28 | Formal Farms = Initial Total Farms*Fraction of Formal Farms | Farm |

Letter “S” and “T” in brackets indicate the subscripts used to represent the five farm-size categories and the two-technology status (Adopters or Non-adopters) respectively.

Table A 2 - List of equations in Cows on Farm stock-flow structure

| Eq.# | Equations | Units |
|------|--|-------------|
| 29 | Survival Fraction[S,T] = 1-Fractional Calf Mortality Rate[S,T] | Dmnl |
| 30 | Calves sold[S,T] = Calves Born[S,T]*(1-Heifer Fraction[S,T])*Survival Fraction[S,T] | heads/Month |
| 31 | Calves Born[S,T] = Cows[S,T]/Calving Interval[S,T] | cows/Month |
| 32 | Net Birth Rate[S,T] = Calves Born[S,T]*Heifer Fraction[S,T]*Survival Fraction[S,T] | head/Month |
| 33 | Calves[S,T] = INTEG (Net Birth Rate[S,T]+Calves Stock Switching[S,T]-Wean Rate[S,T], Initial Heifer Stock[S,T]*(Time to wean[S,T]/Time to First Calving[S,T])) | head |
| 34 | Calves Stock Switching[S,Non-adopters] = -Calves[S,Non-adopters]*Change in Proportion[S]/TIME STEP | head/Month |
| 35 | Calves Stock Switching[S,Adopters] = Calves[S,Non-adopters]*Change in Proportion[S]/TIME STEP | head/Month |
| 36 | Wean Rate[S,T] = Calves[S,T]/Time to wean[S,T] | head/Month |
| 37 | Total Calves = SUM(Calves[S!,T!]) | head |
| 38 | Heifers[S,T] = INTEG (+Heifers Stock Switching[S,T]+Wean Rate[S,T]-First Calving Rate[S,T], Initial Heifer Stock[S,T]*((Time to First Calving[S,T]-Time to wean[S,T])/Time to First Calving[S,T])) | head |
| 39 | Total Heifers = SUM(Heifers[S!,T!]) | head |
| 40 | First Calving Rate[S,T] = Heifers[S,T]/(Time to First Calving[S,T]-Time to wean[S,T]) | head/Month |
| 41 | Time to First Calving[S,T] = Maturation Time[S,T]*(1+STEP(StepHigh AvgMaturationTime, 10)) | Month |
| 42 | Heifers Stock Switching[S,Non-adopters] = -Heifers[S,Non-adopters]*Change in Proportion[S]/TIME STEP | cow/Month |
| 43 | Heifers Stock Switching[S,Adopters] = Heifers[S,Non-adopters]*Change in Proportion[S]/TIME STEP | cow/Month |
| 44 | Heifers Entering[S,T] = Mat 30[S,T] | cows/Month |
| 45 | Cows[S,T] = INTEG (Cow Stock Switching[S,T]+Heifers Entering[S,T]-Cow Cull Rate[S,T], Initial Milk Cows[S,T]*Initial Fraction of Cows in Each Category[S,T]) | cows |
| 46 | Cow Cull Rate[S,T] = Normal Cow Cull Rate[S,T] | cows/Month |
| 47 | Cow Stock Switching[S,Non-adopters] = -Cows[S,Non-adopters]*Change in Proportion[S]/TIME STEP | cow/Mon |
| 48 | Cow Stock Switching[S,Adopters] = Cows[S,Non-adopters]*Change in Proportion[S]/TIME STE | cow/Mon |
| 49 | Total Cows = SUM(Cows[S!,T!]) | cows |

| | | |
|----|--|------------|
| 50 | Cows Per Farm by Size and Technology Level[S,T] = ZIDZ(Cows[S,T],Farms by Category[S,T]) | cows/farm |
| 51 | Cows by Size[S] = SUM(Cows[S,T!]) | cows |
| 52 | Cows Per Farm by Size[S,T] = ZIDZ(SUM(Cows[S,T!]),SUM(Farms by Category[S,T!])) | cows/farm |
| 53 | Short term Cows Adjustment[S,T] = Cows[S,T]*Effect of Expected NFOI on Herd Size("NOFI / Ref NFOI"[S,T]) | cow |
| 54 | NOFI / Ref NFOI[S,T] = NFOI Net Farm Operating Income[S,T]/Reference NFOI[S] | Dmnl |
| 55 | Actual to Desired Cows[S,T] = Short term Cows Adjustment[S,T]-Desired Total Cow Numbers[S,T] | cow |
| 56 | Desired Total Cow Numbers[S,T] = INTEG (Change in Cow Numbers[S,T]+Desired Cow Switching[S,T], Initial Milk Cows[S,T]*Initial Fraction of Cows in Each Category[S,T]) | cow |
| 57 | Desired Cow Switching[S,T] = Cow Stock Switching[S,T] | cow/Month |
| 58 | Change in Cow Numbers[S,T] = Actual to Desired Cows[S,T]/Long term Market Observation Adjustment Time | cow/Month |
| 59 | Relative Desired Total Cow Number[S,T] = MAX(0,XIDZ(Cows[S,T],Desired Total Cow Numbers[S,T],1)) | Dmnl |
| 60 | Effect of Ratio AtoD on Culling[S,T] = IF THEN ELSE(Relative Desired Total Cow Number[S,T] = 0, Maximum Cull Effect[S,T], Relative Desired Total Cow Number[S,T]^Sensitivity of Culling to AD ratio[S,T])*(1-Switch Fixed Ratio)+Switch Fixed Ratio | Dmnl |
| 61 | Maximum Cull Effect[S,T] = (1-Fraction of Cows Involuntarily Culled[S,T])/Initial Voluntary Cull Rate[S,T] | Dmnl |
| 62 | Fraction of Cows Voluntarily Culled[S,T] = Initial Voluntary Cull Rate[S,T]*Effect of Ratio AtoD on Culling[S,T] | 1/Month |
| 63 | Normal Cow Cull Rate[S,T] = Cows[S,T]*MIN(Fraction of Cows Involuntarily Culled[S,T]+Fraction of Cows Voluntarily Culled[S,T],1) | cows/Month |
| 64 | Fraction of Cows Involuntarily Culled[S,T] = 1/(Maturation Time[S,T]+Cows Productive Life[S,T]) | 1/Month |
| 65 | Initial Voluntary Cull Rate[S,T] = (Heifer Fraction[S,T] * Survival Fraction[S,T] / Calving Interval[S,T]) - Fraction of Cows Involuntarily Culled[S,T] | 1/Month |
| 66 | Initial First Calving[S,T] = Initial Milk Cows[S,T]*Initial Fraction of Cows in Each Category[S,T]*(Fraction of Cows Involuntarily Culled[S,T]+Initial Voluntary Cull Rate[S,T]) | cows/Month |
| 67 | Initial Heifer Stock[S,T] = (Initial First Calving[S,T]* Time to First Calving[S,T]) | head |
| 68 | Change in Proportion[S] = IF THEN ELSE(Time>=Begin Change Time, Scenario Implementation[S]*Ramp Switch, 0) | Dmnl |

Table A 3 - List of equations in Heifers maturation time stock-flow structure.

| Eq.# | Equations - | Units |
|------|--|------------|
| 70 | $H\ 1[S,T] = \text{INTEG} (+SH\ 1[S,T] + \text{Wean Rate}[S,T] - \text{Mat}\ 1[S,T], \text{Initial Heifer Stock}[S,T] * (\text{Residual Maturation Time}[S,T] / \text{Time to First Calving}[S,T]))$ | head |
| 71 | $SH\ 1[S, \text{Non-adopters}] = -H\ 1[S, \text{Non-adopters}] * \text{Change in Proportion}[S] / \text{TIME STEP}$ | head/month |
| 72 | $SH\ 1[S, \text{Adopters}] = H\ 1[S, \text{Non-adopters}] * \text{Change in Proportion}[S] / \text{TIME STEP}$ | head/month |
| 73 | $\text{Mat}\ 1[S,T] = H\ 1[S,T] / \text{Residual Maturation Time}[S,T]$ | head/Month |
| 74 | $H\ 2[S,T] = \text{INTEG} (+\text{Mat}\ 1[S,T] + SH\ 2[S,T] - \text{Mat}\ 2[S,T], \text{Initial Heifer Stock}[S,T] * (\text{Residual Maturation Time}[S,T] / \text{Time to First Calving}[S,T]))$ | head |
| 75 | $\text{Mat}\ 2[S,T] = H\ 2[S,T] / \text{Residual Maturation Time}[S,T]$ | head/Month |
| 76 | $SH\ 2[S, \text{Non-adopters}] = -H\ 2[S, \text{Non-adopters}] * \text{Change in Proportion}[S] / \text{TIME STEP}$ | head/Month |
| 77 | $SH\ 2[S, \text{Adopters}] = H\ 2[S, \text{Non-adopters}] * \text{Change in Proportion}[S] / \text{TIME STEP}$ | head/Month |
| 78 | $\text{Residual Maturation Time}[S,T] = (\text{Time to First Calving}[S,T] - \text{Time to wean}[S,T]) / \text{Number of Heifer Category}$ | Month |
| 79 | Number of Heifer Category = 30 | Dmnl |

Same structure until SH 30 representing the 30th cohort of heifers' maturation time.

Table A 4 - List of equations in Replacement cow price stock-flow structure.

| Eq.# | Equations | Units |
|------|---|--------------|
| 80 | Formal Initial Milk Cows[S,T] = (Initial Milk Cows[S,T]*Fraction of Formal Production)-(Initial Milk Cows[S,T]*Minimum Fraction of Specialized Milk Cows) | cow |
| 81 | Reference Cull Rate[S,T] = (Fraction of Cows Involuntarily Culled[S,T]+Initial Voluntary Cull Rate[S,T])*Formal Initial Milk Cows[S,T]*Initial Fraction of Cows in Each Category[S,T] | cows/Month |
| 82 | Sum Ref Cull Rate = SUM(Reference Cull Rate[S!,T!]) | cow/Month |
| 83 | Ratio Sum to Ref Cull Rate = Sum Cull Rate/SUM(Reference Cull Rate[S!,T!]) | 1 |
| 84 | Sum Cull Rate = SUM(Formal Cow Cull Rate[S!,T!]) | cow/Month |
| 85 | Formal Cow Cull Rate[S,T] =(Cow Cull Rate[S,T]*Fraction of Formal Production)-(Cow Cull Rate[S,T]*Minimum Fraction of Specialized Milk Cows) | cow/Month |
| 86 | Indicated Cull Cow Price = Reference Cull Cow Price*Ratio Sum to Ref Cull Rate^Sensitivity of Cull Cow Price to Relative Culling Rate | \$/cow |
| 87 | Change in Cow Cull Price = (Indicated Cull Cow Price-Cull Cow Price)/Cull Cow Price Adjustment Time | \$/cow/Month |
| 88 | Cull Cow Price = INTEG (Change in Cow Cull Price,Reference Cull Cow Price) | \$/cow |
| 89 | Calf Price = Cull Cow Price*Fraction Paid for Calf | \$/cow |
| 90 | Value of Calves Sold[S,T] = Calf Price*Formal Calves Sold[S,T] | \$/Month |
| 91 | Formal Calves Sold[S,T] =(Calves sold[S,T]*Fraction of Formal Production)-(Calves sold[S,T]*Minimum Fraction of Specialized Milk Cows) | Heads/Month |
| 92 | Value of Cull Cows Sold[S,T]= ACTIVE INITIAL (Formal Cow Cull Rate[S,T]*Cull Cow Price, Reference Cull Rate[S,T]*Reference Cull Cow Price) | \$/Month |
| 93 | Value of Livestock Sales[S,T] = (Value of Calves Sold[S,T]+Value of Cull Cows Sold[S,T])*(1-DATA SOURCE ADJUSTMENT) | \$/Month |
| 94 | Reference Cull Cow Price = ("Beef price (cow) 2005-2015"*Cow's weight)*(1-Cows price discount)*(1-"Switch Beef Price Data on-off")+((Beef Price Data*Cow's weight)*(1-Cows price discount))*"Switch Beef Price Data on-off" | \$/cow |

Table A 5 - List of equations in Net farm operation income (NFOI) stock-flow structure.

| Eq.# | Equations | Units |
|------|---|---------------|
| 95 | Feed Cost Per Liter[S,T]= (((Ration Price*Units of ration per liters of milk[S,T])+Other feed costs[S,T])*(1-"Switch Data Ration Price on-off"))+((Ration Price Data*Units of ration per liters of milk[S,T])+Other feed costs[S,T])*"Switch Data Ration Price on-off") | \$/Liter |
| 96 | Feed Costs[S,T] = (Feed Cost Per Liter[S,T]*Milk Production Per Farm[S,T]) | \$/Month/farm |
| 97 | Replacements Cost[S,T] = Monthly Farm Receipts[S,T]*Fraction of replacement cost of total revenue[S,T] | \$/Month/farm |
| 98 | Operational Effective Cost[S,T] = Feed Costs[S,T]+Hired Labor Costs[S,T]+Other Costs per Month[S,T]+Replacements Cost[S,T] | \$/Month/farm |
| 99 | Other Costs per Month[S,T] = (Average Cows per Farm[S,T]*Other Costs per Cow[S,T])*(1-"Switch Other Farm Cost Growth Rate on-off")+Average Cows per Farm[S,T]*(Other Costs per Cow[S,T]+Addition to Other Costs)*"Switch Other Farm Cost Growth Rate on-off" | \$/Month/farm |
| 100 | Average Cows per Farm[S,T] = ZIDZ(Reference Cows on Farms[S,T],Farms by Category[S,T]) | cows/farm |
| 101 | Hired Labor Costs[S,T] = IF THEN ELSE("Switch Wage Growth on-off"=0, (Hired Labor Wage[S,T]*Hired Labor Hours Required[S,T]), (Hired Labor Wage[S,T]*Hired Labor Hours Required[S,T])) | \$/Month/farm |
| 102 | Hired Labor Hours Required[S,T] = Total Labor Hours Required[S,T]*(1-Fraction of family Labor Used[S,T]) | man/farm |
| 103 | Total Labor Hours Required[S,T] = Milk Production Per Farm[S,T]/(Average Labor Productivity[S,T]*Days per month) | man/farm |
| 104 | NFOI Net Farm Operating Income[S,T] = (Monthly Farm Receipts[S,T]-Operational Effective Cost[S,T]) | \$/Month/farm |
| 105 | Monthly Farm Receipts[S,T] =Value of Livestock Sales per farm[S,T]+Value of Milk Sold[S,T] | \$/Month/farm |
| 106 | Value of Livestock Sales per farm[S,T] = ZIDZ(Value of Livestock Sales[S,T],Farms by Category[S,T]) | \$/Month/farm |
| 107 | Value of Milk Sold[S,T] = Current Farm Milk Price*Milk Production Per Farm[S,T] | \$/Month/farm |
| 108 | "NFOI - W.Avg"= SUM(NFOI Net Farm Operating Income[S!,T!]*Farm Proportion[S!,T!]) | \$/Month/farm |

Table A 6 - List of equations in Dairy products price stock-flow structure.

| Eq.# | Equations | Units |
|------|--|-------------|
| 109 | Inventory[Product]= INTEG (Production[Product]+ "Net Fluid Import-Export"[Product]-Sales[Product], Initial Inventory[Product]) | Liters |
| 110 | Sales[Product] = MIN(Final Domestic Demand[Product],Inventory[Product]/Minimum Residence Time [Product]) | Liter/Month |
| 111 | Final Domestic Demand[Product] = SMOOTHI(Indicated Final Domestic Demand[Product], Demand Adjustment Time[Product], Domestic Final Demand Input[Product]) | Liter/Month |
| 112 | Domestic Final Demand Input[Product] = Reference Final Domestic Demand[Product]*(1-"switch demand growth on-off")+Demand Data[Product]*"switch demand growth on-off" | Liter/Mont |
| 113 | Indicated Final Domestic Demand[Product] = Domestic Final Demand Input[Product]*"Retail Price/Ref Retail Price"[Product]^Sensitivity of Demand to Price[Product] | Liter/Month |
| 114 | Retail Price/Ref Retail Price[Product] = IF THEN ELSE(Switch Retail Inflation Price=1, Retail Price[Product]/(Reference Retail Price[Product]*Consumer Price Index of Dairy Product[Product]*Proportion Due to Inflation[Product]), Retail Price[Product]/(Reference Retail Price[Product])) | 1 |
| 115 | Retail Price[Product] = ("Processor's Price (Wholesale price)"[Product]+Retail Markup[Product]) | \$/Liter |
| 116 | Processor's Price (Wholesale price)[Product] = ("Reference Processor's Price (Wholesale price)"[Product]*Relative Inventory Coverage[Product]^Sensitivity of Price to Inventory Coverage[Product]) | \$/Liter |
| 117 | Relative Inventory Coverage[Product]= Inventory Coverage[Product]/Reference Inventory Coverage[Product] | Dmnl |
| 118 | Inventory Coverage[Product] = Inventory[Product]/Sales[Product] | Month |
| 119 | Initial Inventory[Product] = Reference Inventory Coverage[Product]*Reference Final Domestic Demand[Product] | Liter |
| 120 | Production[Product] = Milk Allocation with Balancing[Product]/Raw Milk Input Proportion[Product] | Liter/Month |
| 121 | Net Fluid Import-Export[Product] = IF THEN ELSE(Switch Trade Data on-off=0, Import[Product]-Export[Product], Import Data[Product]-Export Data[Product]) | Liter/Month |
| 122 | Indicated Milk Allocation[Product] = Processing Capacity[Product]*Utilization[Product]*Raw Milk Input Proportion[Product] | Liter/Month |
| 123 | Processing Capacity[Product] = Reference Production[Product]/Reference Utilization[Product] | Liter/Month |
| 124 | Utilization[Product] = SMOOTHI(Indicated Utilization[Product],Utilization Adjustment Time[Product], Reference Utilization[Product]) | Dmnl |
| 125 | Indicated Utilization[Product] = Reference Utilization[Product]*Effect of PD on Utilization(Proportional Diff[Product]) | Dmnl |

| | | |
|-----|---|----------|
| 126 | $\text{Proportional Diff[Product]} = (\text{Unit Net Margin[Product]} - \text{Reference Unit Net Margin[Product]}) / \text{Reference Unit Net Margin[Product]}$ | Dmnl |
| 127 | $\text{Unit Net Margin[Product]} = (\text{Processor's Price (Wholesale price)[Product]} - \text{Unit Processing Cost[Product]} - \text{Cost of Raw Material[Product]})$ | \$/Liter |
| 128 | $\text{Cost of Raw Material[Product]} = \text{Price of Milk for Product[Product]} * \text{Raw Milk Input Proportion[Product]}$ | \$/Liter |

Table A 7 - List of equations in Milk price stock-flow structure.

| Eq.# | Equations | Units |
|------|--|----------------|
| 129 | Profit Margin by Product[Product] = Reference Unit Net Margin[Product]/Reference Processor's Price (Wholesale price)[Product] | Dmnl |
| 130 | Price of Milk for Product[Product] = ("Processor's Price (Wholesale price)"[Product]*(1-Profit Margin by Product[Product])-Unit Processing Cost[Product])/Raw Milk Input Proportion[Product] | \$/Liter |
| 131 | Relative Farm Milk Price[Product] = Price of Milk for Product[Product]/Reference Farm Price (2005) | Dmnl |
| 132 | Allocate Milk by Priority[Product] = ALLOCATE BY PRIORITY(Indicated Milk Allocation[Product], Relative Farm Milk Price[Product], Allocation Size, Width, Milk Production | Liter/Month |
| 133 | Milk Allocation with Balancing[Fluid]= Allocate Milk by Priority[Fluid] | Liter/Month |
| 134 | Milk Allocation with Balancing[Storable]=Allocate Milk by Priority[Storable] | Liter/Month |
| 135 | Milk Allocation with Balancing[Soft] = Allocate Milk by Priority[Soft] | Liter/Month |
| 136 | Milk Allocation with Balancing[Balancing] = MAX(Allocate Milk by Priority[Balancing],Milk Production-Allocate Milk by Priority[Fluid]-Allocate Milk by Priority[Storable]-Allocate Milk by Priority[Soft]) | Liter/Month |
| 137 | Total Value of Farm Milk = SUM(Milk Allocation with Balancing[Product!]*Price of Milk for Product[Product!]) | \$/Month |
| 138 | Expected Farm Milk price = MAX(Total Value of Farm Milk/Milk Production,0) | \$/Liter |
| 139 | Change in Farm Milk Price= (Expected Farm Milk price-Current Farm Milk Price)/Farm Price Adjustment Time | \$/Liter/Month |
| 140 | Current Farm Milk Price = INTEG (Change in Farm Milk Price, Reference Farm Price (2005)) | \$/Liter |

Table A 8 - List of parameters used by module, current and improved value for technology level, units and source – Milk production stock-flow structure.

| # | Parameters | Units | Current Value ^a | Improved Value ^b | Source |
|----|--|---------------|----------------------------|-----------------------------|--------------------------------------|
| 1 | Reference Milk Price over Feed Price Ratio | Dmnl | 3.255 | - | Estimated on D.E. ^c |
| 2 | Sensitivity of Milk Per Cow over Milk Price Feed Cost ratio | Dmnl | 0.1917 | - | Estimated on D.E. |
| 3 | Reference Fraction of Potential Expressed | Dmnl | 0.6163 | - | Specialists' opinion |
| 4 | Initial Fraction of Potential Expressed | Dmnl | 0.6163 | - | Specialists' opinion |
| 5 | Production Practice Adjustment Time | Month | 2.0 | - | Estimated |
| 6 | Potential Milk per Cow Growth Rate | 1/year | 0.02 | - | Calibrated and specialist opinion |
| 7 | Switch Potential Milk per Cow Growth Rate on-off | Dmnl | 1-on 0-off | - | N/A |
| 8 | Initial Maximum Potential Milk per Cow per day["<50",T] | Liter/cow/day | 6.99 | 9.73 | Literature and specialists' opinion |
| 9 | Initial Maximum Potential Milk per Cow per day["51-200",T] | Liter/cow/day | 9.9 | 16.22 | Literature and specialists' opinion |
| 10 | Initial Maximum Potential Milk per Cow per day["201-500",T] | Liter/cow/day | 13.4 | 20.28 | Literature and specialists' opinion |
| 11 | Initial Maximum Potential Milk per Cow per day["501-1000",T] | Liter/cow/day | 17.0 | 24.34 | Literature and specialists' opinion |
| 12 | Initial Maximum Potential Milk per Cow per day[">1000",T] | Liter/cow/day | 20.9 | 29.20 | Literature and specialists' opinion |
| 13 | Switch Seasonality | Dmnl | 1-on 0-off | - | N/A |
| 14 | Seasonality Amplitude["<50",T] | Dmnl | 0.184 | 0.122 | Calculated and Specialists' opinion |
| 15 | Seasonality Amplitude["51-200",T] | Dmnl | 0.143 | 0.102 | Estimated based on official database |
| 16 | Seasonality Amplitude["201-500",T] | Dmnl | 0.102 | 0.082 | Estimated based on official database |
| 17 | Seasonality Amplitude["501-1000",T] | Dmnl | 0.082 | 0.061 | Estimated based on official database |
| 18 | Seasonality Amplitude[">1000",T] | Dmnl | 0.065 | 0.061 | Estimated based on official database |

| | | | | | |
|----|--|------------|-----------|---|--------------------------------------|
| 19 | Seasonality Period | Month | 12 | - | Estimated based on official database |
| 20 | Peak Month Yield | Month | 11 | - | Calibrated to match reference line |
| 21 | Month per year | Month/year | 12 | - | N/A |
| 22 | Days per month | Day/month | 30.42 | - | N/A |
| 23 | Minimum Fraction of Specialized Milk Cows | Dmnl | 0.112 | - | Calculated |
| 24 | Fraction of Formal Production | Dmnl | 0.661 | - | Official database |
| 25 | Minimum Fraction of Specialized Dairy Farm | Dmnl | 0.272 | - | Calculated |
| 26 | Fraction of Formal Farms | Dmnl | 0.689 | - | Calculated |
| 27 | Initial Total Farms | Farms | 1,350,809 | - | Official database |

^a All parameters are imported from a spreadsheet using the appropriated Vensim function.

^b Improved Values are reported only if there are difference from Current Value.

^c Estimated on DE - Parameter estimated in dynamic equilibrium condition

Table A 9 - List of parameters used by module, current and improved value for technology level, units and source – Cows on farm stock-flow structure.

| # | Parameters | Units | Current Value ^a | Improved Value ^b | Source |
|----|--|-------|----------------------------|-----------------------------|-------------------------------------|
| 28 | Fractional Calf Mortality Rate["<50",T] | Dmnl | 0.0067 | - | Literature and specialists opinion |
| 29 | Fractional Calf Mortality Rate["51-200",T] | Dmnl | 0.0067 | - | Literature and specialists opinion |
| 30 | Fractional Calf Mortality Rate["201-500",T] | Dmnl | 0.0067 | - | Literature and specialists opinion |
| 31 | Fractional Calf Mortality Rate["501-1000",T] | Dmnl | 0.0067 | - | Literature and specialists opinion |
| 32 | Fractional Calf Mortality Rate[">1000",T] | Dmnl | 0.0067 | - | Literature and specialists opinion |
| 33 | Heifer Fraction["<50",T] | Dmnl | 0.50 | 0.60 | Literature and specialists opinion |
| 34 | Heifer Fraction["51-200",T] | Dmnl | 0.50 | 0.60 | Literature and specialists opinion |
| 35 | Heifer Fraction["201-500",T] | Dmnl | 0.55 | 0.63 | Literature and specialists opinion |
| 36 | Heifer Fraction["501-1000",T] | Dmnl | 0.60 | 0.65 | Literature and specialists opinion |
| 37 | Heifer Fraction[">1000",T] | Dmnl | 0.60 | 0.65 | Literature and specialists opinion |
| 38 | Calving Interval["<50",T] | month | 13.00 | 12.67 | Calculated and Specialists' opinion |
| 39 | Calving Interval["51-200",T] | month | 13.95 | 12.67 | Calculated and Specialists' opinion |
| 40 | Calving Interval["201-500",T] | month | 13.74 | 12.67 | Calculated and Specialists' opinion |
| 41 | Calving Interval["501-1000",T] | month | 13.75 | 12.34 | Calculated and Specialists' opinion |

| | | | | | |
|----|------------------------------------|-------|-------|-------|-------------------------------------|
| 42 | Calving Interval[">1000",T] | month | 13.31 | 12.50 | Calculated and Specialists' opinion |
| 43 | Maturation Time["<50",T] | month | 35.81 | - | Calculated and Specialists' opinion |
| 44 | Maturation Time["51-200",T] | month | 35.57 | - | Calculated and Specialists' opinion |
| 45 | Maturation Time["201-500",T] | month | 36.55 | - | Calculated and Specialists' opinion |
| 46 | Maturation Time["501-1000",T] | month | 35.77 | - | Calculated and Specialists' opinion |
| 47 | Maturation Time[">1000",T] | month | 34.54 | - | Calculated and Specialists' opinion |
| 48 | Time to wean["<50",T] | month | 4.77 | 3.50 | Calculated and Specialists' opinion |
| 49 | Time to wean["51-200",T] | month | 4.00 | 3.00 | Calculated and Specialists' opinion |
| 50 | Time to wean["201-500",T] | month | 3.47 | 2.50 | Calculated and Specialists' opinion |
| 51 | Time to wean["501-1000",T] | month | 2.93 | 2.50 | Calculated and Specialists' opinion |
| 52 | Time to wean[">1000",T] | month | 2.40 | 2.00 | Calculated and Specialists' opinion |
| 53 | Cows Productive Life["<50",T] | month | 80 | - | Specialists' opinion |
| 54 | Cows Productive Life["51-200",T] | month | 80 | - | Specialists' opinion |
| 55 | Cows Productive Life["201-500",T] | month | 80 | - | Specialists' opinion |
| 56 | Cows Productive Life["501-1000",T] | month | 80 | - | Specialists' opinion |
| 57 | Cows Productive Life[">1000",T] | month | 80 | - | Specialists' opinion |

| | | | | | |
|----|---|---------------|------------|---|-----------------------------------|
| 58 | Effect of Expected NFOI on Herd Size* | Dmnl | Lookup | - | Estimated based on previous model |
| 59 | Reference NFOI["<50"] | \$/month/farm | 202.64 | - | Calibrated |
| 60 | Reference NFOI["51-200"] | \$/month/farm | 606.15 | - | Calibrated |
| 61 | Reference NFOI["201-500"] | \$/month/farm | 1,662.04 | - | Calibrated |
| 62 | Reference NFOI["501-1000"] | \$/month/farm | 3,405.64 | - | Calibrated |
| 63 | Reference NFOI[">1000"] | \$/month/farm | 12,087.08 | - | Calibrated |
| 64 | Long term Market Observation Adjustment Time | month | 12 | - | Estimated |
| 65 | Sensitivity of Culling to AD ratio | Dmnl | 0.733 | - | Calibrated |
| 66 | Initial Milk Cows | cows | 20,022,725 | - | Official database |
| 67 | Initial Fraction of Cows in Each Category["<50",T] | Dmnl | 0.15 | - | Literature |
| 68 | Initial Fraction of Cows in Each Category["51-200",T] | Dmnl | 0.30 | - | Literature |
| 69 | Initial Fraction of Cows in Each Category["201-500",T] | Dmnl | 0.24 | - | Literature |
| 70 | Initial Fraction of Cows in Each Category["501-1000",T] | Dmnl | 0.12 | - | Literature |
| 71 | Initial Fraction of Cows in Each Category[">1000",T] | Dmnl | 0.19 | - | Literature |
| 72 | Scenario Implementation[S] - BASE | Dmnl | 0.0 | - | Literature |
| 73 | Scenario Implementation[S] - SLOW | Dmnl | 0.0002497 | - | Literature |
| 74 | Scenario Implementation[S] - MED | Dmnl | 0.0013647 | - | Literature |
| 75 | Scenario Implementation[S] - FAST | Dmnl | 0.0024663 | - | Literature |

* represented separately after the parameters table.

Table A 10 - List of parameters used by module, current and improved value for technology level, units and source – Milk price stock-flow structure.

| Eq.# | Parameters | Units | Current Value^a | Improved Value^b | Source |
|-------------|-----------------------------|--------------|----------------------------------|-----------------------------------|-------------------|
| 76 | Width | Dmnl | 25 | - | Estimated |
| 77 | Allocation Size | Dmnl | 4 | - | Calculated |
| 78 | Farm Price Adjustment Time | Month | 1 | - | Estimated |
| 79 | Reference Farm Price (2005) | \$/Liter | 0.5218 | - | Official database |

Table A 11 - List of parameters used by module, current and improved value for technology level, units and source – Replacement cow price stock-flow structure.

| Eq.# | Parameters | Units | Current Value ^a | Improved Value ^b | Source |
|------|--|-------|----------------------------|-----------------------------|----------------------|
| 80 | Sensitivity of Cull Cow Price to Relative Culling Rate | Dmnl | -1.80 | - | Estimated |
| 81 | Cull Cow Price Adjustment Time | month | 3 | - | Estimated |
| 82 | Fraction Paid for Calf | Dmnl | 0.1 | - | Estimated |
| 83 | Cows price discount | Dmnl | 0.000694 | - | Calibrated |
| 84 | Beef Price Data | \$/@ | Time series | | Official database |
| 85 | Avg beef price (cow) 2005-2015 | \$/@ | 50.09 | - | Official database |
| 86 | Cow's weight | @/cow | 15.24 | - | Specialists' opinion |
| 87 | Data source adjustment | Dmnl | 0.41 | - | Estimated |
| 88 | Switch Beef Price Data on-off | Dmnl | 1-on 0-off | - | N/A |

Table A 12 - List of parameters used by module, current and improved value for technology level, units and source – Net farm operation income stock-flow structure.

| Eq.# | Parameters | Units | Current Value ^a | Improved Value ^b | Source |
|------|---|--------------|----------------------------|-----------------------------|-------------------|
| 89 | Ration Price Data | \$/kg | Time series | | Official database |
| 90 | "Switch Data Ration Price on-off" | Dmnl | 1-on 0-off | - | N/A |
| 91 | Average Ration Price | \$/kg | 0.379 | - | Official database |
| 92 | Units of ration per liters of milk["<50",T] | kg/Liter | 0.182 | 0.181 | Estimated |
| 93 | Units of ration per liters of milk["51-200",T] | kg/Liter | 0.296 | 0.283 | Estimated |
| 94 | Units of ration per liters of milk["201-500",T] | kg/Liter | 0.334 | 0.262 | Estimated |
| 95 | Units of ration per liters of milk["501-1000",T] | kg/Liter | 0.351 | 0.264 | Estimated |
| 96 | Units of ration per liters of milk[">1000",T] | kg/Liter | 0.351 | 0.288 | Estimated |
| 97 | Other feed costs["<50",T] | \$/Liter | 0.0548 | 0.0481 | Estimated |
| 98 | Other feed costs["51-200",T] | \$/Liter | 0.0597 | 0.0765 | Estimated |
| 99 | Other feed costs["201-500",T] | \$/Liter | 0.0650 | 0.0579 | Estimated |
| 100 | Other feed costs["501-1000",T] | \$/Liter | 0.0697 | 0.0656 | Estimated |
| 101 | Other feed costs[">1000",T] | \$/Liter | 0.0842 | 0.0844 | Estimated |
| 102 | Fraction of replacement cost of total revenue["<50",T] | Dmnl | 0.378 | 0.267 | Estimated |
| 103 | Fraction of replacement cost of total revenue["51-200",T] | Dmnl | 0.278 | 0.2120 | Estimated |
| 104 | Fraction of replacement cost of total revenue["201-500",T] | Dmnl | 0.205 | 0.137 | Estimated |
| 105 | Fraction of replacement cost of total revenue["501-1000",T] | Dmnl | 0.163 | 0.112 | Estimated |
| 106 | Fraction of replacement cost of total revenue[">1000",T] | Dmnl | 0.158 | 0.109 | Estimated |
| 107 | Other Costs per Cow["<50",T] | \$/Month/cow | 8.31 | 11.93 | Estimated |
| 108 | Other Costs per Cow["51-200",T] | \$/Month/cow | 11.03 | 17.50 | Estimated |

| | | | | | |
|-----|---|----------------|------------|-------|-------------------|
| 109 | Other Costs per Cow["201-500",T] | \$/Month/cow | 16.26 | 23.69 | Estimated |
| 110 | Other Costs per Cow["501-1000",T] | \$/Month/cow | 23.58 | 31.48 | Estimated |
| 111 | Other Costs per Cow[">1000",T] | \$/Month/cow | 30.59 | 36.8 | Estimated |
| 112 | "Switch Other Farm Cost Growth Rate on-off" | Dmnl | 1-on 0-off | - | N/A |
| 113 | Hired Labor Wage[S,T] | \$/man/Month | 537.83 | - | Official database |
| 114 | Wage Growth Rate[S,T] | 1/Month | 0.0125 | - | Official database |
| 115 | Switch Wage Growth on-off | Dmnl | 1-on 0-off | - | N/A |
| 116 | Fraction of family Labor Used["<50",T] | Dmnl | 0.89 | - | Literature |
| 117 | Fraction of family Labor Used["51-200",T] | Dmnl | 0.65 | - | Literature |
| 118 | Fraction of family Labor Used["201-500",T] | Dmnl | 0.49 | - | Literature |
| 119 | Fraction of family Labor Used["501-1000",T] | Dmnl | 0.30 | - | Literature |
| 120 | Fraction of family Labor Used[">1000",T] | Dmnl | 0.25 | - | Literature |
| 121 | Average Labor Productivity["<50",T] | Liters/man/day | 64 | - | Literature |
| 122 | Average Labor Productivity["51-200",T] | Liters/man/day | 121 | - | Literature |
| 123 | Average Labor Productivity["201-500",T] | Liters/man/day | 194 | - | Literature |
| 124 | Average Labor Productivity["501-1000",T] | Liters/man/day | 297 | - | Literature |
| 125 | Average Labor Productivity[">1000",T] | Liters/man/day | 525 | - | Literature |
| 126 | Inflation Cost by Year[Period]* | | | | |
| 127 | Year 1 | Dmnl | -10 | - | Calibrated |
| 128 | Year 2 | Dmnl | 8 | - | Calibrated |
| 129 | Year 3 | Dmnl | -18 | - | Calibrated |
| 130 | Year 4 | Dmnl | 26 | - | Calibrated |

| | | | | |
|-----|---------|------|-----|--------------|
| 131 | Year 5 | Dmnl | -12 | - Calibrated |
| 132 | Year 6 | Dmnl | 30 | - Calibrated |
| 133 | Year 7 | Dmnl | 22 | - Calibrated |
| 134 | Year 8 | Dmnl | 14 | - Calibrated |
| 135 | Year 9 | Dmnl | -8 | - Calibrated |
| 136 | Year 10 | Dmnl | 39 | - Calibrated |
| 137 | Year 11 | Dmnl | 39 | - Calibrated |
| 138 | Year 12 | Dmnl | 35 | - Calibrated |
| 139 | Year 13 | Dmnl | 1 | - Calibrated |

Table A 13 - List of parameters used by module, current and improved value for technology level, units and source – Dairy products price stock-flow structure.

| Eq.# | Parameters | Units | Current Value | Improved Value | Source |
|------|--|-------------|---------------|----------------|---------------------|
| 140 | Import Data[Balancing] | Liter/Month | Time series | | Official database |
| 141 | Import Data[Fluid] | Liter/Month | Time series | | Official database |
| 142 | Import Data[Soft] | Liter/Month | Time series | | Official database |
| 143 | Import Data[Storable] | Liter/Month | Time series | | Official database |
| 144 | Switch Trade Data on-off | Dmnl | 1-on 0-off | | - N/A |
| 145 | Demand Adjustment Time[Fluid] | Month | 1 | | - Estimated |
| 146 | Demand Adjustment Time[Storable] | Month | 1 | | - Estimated |
| 147 | Demand Adjustment Time[Soft] | Month | 2 | | - Estimated |
| 148 | Demand Adjustment Time[Balancing] | Month | 2 | | - Estimated |
| 149 | Minimum Residence Time[Product] | Month | 0.125 | | - Estimated |
| 150 | Demand Data[Fluid] | Liter/Month | Time series | | Official database |
| 151 | Demand Data[Storable] | Liter/Month | Time series | | Official database |
| 152 | Demand Data[Soft] | Liter/Month | Time series | | Official database |
| 153 | Demand Data[Balancing] | Liter/Month | Time series | | Official database |
| 154 | Reference Final Domestic Demand[Fluid] | unit/Month | 515,709,472 | | - Official database |
| 155 | Reference Final Domestic Demand[Storable] | unit/Month | 37,004,196 | | - Official database |
| 156 | Reference Final Domestic Demand[Soft] | unit/Month | 28,093,160 | | - Official database |
| 157 | Reference Final Domestic Demand[Balancing] | unit/Month | 97,611,664 | | - Official database |
| 158 | Sensitivity of Demand to Price[Fluid] | Dmnl | -1.501 | | - Literature |

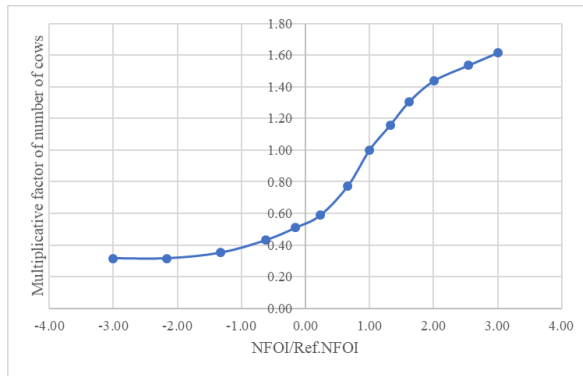
| | | | | |
|-----|--|---------|-------------|-----------------------------|
| 159 | Sensitivity of Demand to Price[Storable] | Dmnl | -1.164 | - Literature |
| 160 | Sensitivity of Demand to Price[Soft] | Dmnl | -1.501 | - Literature |
| 161 | Sensitivity of Demand to Price[Balancing] | Dmnl | -0.863 | - Literature |
| 162 | Reference Retail Price[Fluid] | \$/unit | 1.58 | - Official database |
| 163 | Reference Retail Price[Storable] | \$/unit | 10.78 | - Official database |
| 164 | Reference Retail Price[Soft] | \$/unit | 5.54 | - Official database |
| 165 | Reference Retail Price[Balancing] | \$/unit | 15.03 | - Official database |
| 166 | Proportion Due to Inflation[Fluid] | Dmnl | 0.96 | - Estimated |
| 167 | Proportion Due to Inflation[Storable] | Dmnl | 0.15 | - Estimated |
| 168 | Proportion Due to Inflation[Soft] | Dmnl | 0.15 | - Estimated |
| 169 | Proportion Due to Inflation[Balancing] | Dmnl | 1.01 | - Estimated |
| 170 | Consumer Price Index of Dairy Product[Fluid] | Dmnl | Time series | Official database |
| 171 | Consumer Price Index of Dairy Product[Storable] | Dmnl | Time series | Official database |
| 172 | Consumer Price Index of Dairy Product[Soft] | Dmnl | Time series | Official database |
| 173 | Consumer Price Index of Dairy Product[Balancing] | Dmnl | Time series | Official database |
| 174 | Retail Markup[Fluid] | \$/unit | 0.40 | - Estimated and specialists |
| 175 | Retail Markup[Storable] | \$/unit | 3.33 | - Estimated and specialists |
| 176 | Retail Markup[Soft] | \$/unit | 3.67 | - Estimated and specialists |
| 177 | Retail Markup[Balancing] | \$/unit | 6.48 | - Estimated and specialists |
| 178 | "Reference Processor's Price (Wholesale price)"[Fluid] | \$/unit | 1.17 | - Official database |

| | | | | | |
|-----|--|---------|--------|---|---------------------------|
| 179 | "Reference Processor's Price (Wholesale price)"[Storable] | \$/unit | 7.45 | - | Official database |
| 180 | "Reference Processor's Price (Wholesale price)"[Soft] | \$/unit | 1.87 | - | Official database |
| 181 | "Reference Processor's Price (Wholesale price)"[Balancing] | \$/unit | 8.55 | - | Official database |
| 182 | Sensitivity of Price to Inventory Coverage[Fluid] | Dmnl | -0.50 | - | Estimated and specialists |
| 183 | Sensitivity of Price to Inventory Coverage[Storable] | Dmnl | -0.35 | - | Estimated and specialists |
| 184 | Sensitivity of Price to Inventory Coverage[Soft] | Dmnl | -0.50 | - | Estimated and specialists |
| 185 | Sensitivity of Price to Inventory Coverage[Balancing] | Dmnl | -0.100 | - | Estimated and specialists |
| 186 | Reference Inventory Coverage[Fluid] | month | 2.00 | - | Estimated and specialists |
| 187 | Reference Inventory Coverage[Storable] | month | 4.00 | - | Estimated and specialists |
| 188 | Reference Inventory Coverage[Soft] | month | 4.00 | - | Estimated and specialists |
| 189 | Reference Inventory Coverage[Balancing] | month | 6.00 | - | Estimated and specialists |
| 190 | Unit Processing Cost[Fluid] | \$/unit | 0.34 | - | Previous model |
| 191 | Unit Processing Cost[Storable] | \$/unit | 1.23 | - | Previous model |
| 192 | Unit Processing Cost[Soft] | \$/unit | 0.53 | - | Previous model |
| 193 | Unit Processing Cost[Balancing] | \$/unit | 1.07 | - | Previous model |
| 194 | Reference Unit Net Margin[Fluid] | \$/unit | 0.31 | - | Previous model |
| 195 | Reference Unit Net Margin[Storable] | \$/unit | 2.16 | - | Previous model |
| 196 | Reference Unit Net Margin[Soft] | \$/unit | 0.87 | - | Previous model |
| 197 | Reference Unit Net Margin[Balancing] | \$/unit | 4.70 | - | Previous model |
| 198 | Utilization Adjustment Time[Fluid] | month | 1 | - | Previous model |
| 199 | Utilization Adjustment Time[Storable] | month | 2 | - | Previous model |
| 200 | Utilization Adjustment Time[Soft] | month | 2 | - | Previous model |

| | | | | | |
|-----|--|-------------|-------------|---|-----------------------------------|
| 201 | Utilization Adjustment Time[Balancing] | month | 3 | - | Previous model |
| 202 | Reference Utilization[Fluid] | Dmnl | 0.8 | - | Estimated |
| 203 | Reference Utilization[Storable] | Dmnl | 0.8 | - | Estimated |
| 204 | Reference Utilization[Soft] | Dmnl | 0.8 | - | Estimated |
| 205 | Reference Utilization[Balancing] | Dmnl | 0.8 | - | Estimated |
| 206 | Reference Production[Fluid] | Liter/Month | 515,552,093 | - | Official database |
| 207 | Reference Production[Storable] | Liter/Month | 37,673,400 | - | Official database |
| 208 | Reference Production[Soft] | Liter/Month | 28,097,397 | - | Official database |
| 209 | Reference Production[Balancing] | Liter/Month | 100,140,572 | - | Official database |
| 210 | Raw Milk Input Proportion[Fluid] | Dmnl | 1.015 | | Official database |
| 211 | Raw Milk Input Proportion[Storable] | Dmnl | 7.692 | | Official database |
| 212 | Raw Milk Input Proportion[Soft] | Dmnl | 0.870 | | Official database |
| 213 | Raw Milk Input Proportion[Balancing] | Dmnl | 5.189 | | Official database |
| 214 | Effect of PD on Utilization* | Dmnl | Lookup | - | Estimated based on previous model |

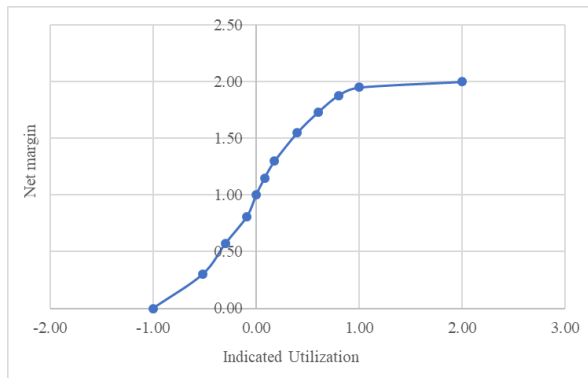
*represented separately after the parameters table.

Figure A1 - Lookup function of Effect of Expected NFOI on Herd Size referent equation 58



| Relative NFOI | #Cows |
|---------------|-------|
| -3.00 | 0.32 |
| -2.17 | 0.32 |
| -1.33 | 0.35 |
| -0.62 | 0.43 |
| -0.15 | 0.51 |
| 0.23 | 0.59 |
| 0.66 | 0.77 |
| 1.00 | 1.00 |
| 1.32 | 1.16 |
| 1.62 | 1.31 |
| 2.01 | 1.44 |
| 2.54 | 1.54 |
| 3.00 | 1.61 |

Figure A2 - Lookup function of Net Margin Proportional Difference on Indicated Utilization



| Net margin | Indicated Utilization |
|------------|-----------------------|
| -1.00 | 0.00 |
| -0.52 | 0.30 |
| -0.30 | 0.57 |
| -0.09 | 0.81 |
| 0.00 | 1.00 |
| 0.08 | 1.15 |
| 0.18 | 1.30 |
| 0.40 | 1.55 |
| 0.60 | 1.73 |
| 0.80 | 1.88 |
| 1.00 | 1.95 |
| 2.00 | 2.00 |

APPENDIX - B

Table B1 – Specialists name by institution.

| Spc.# | Name | Institution |
|--------------|-----------------------------|------------------------------------|
| 1 | Andrew M. Novakovic | Cornell University |
| 2 | Charles F. Nicholson | Cornell University |
| 3 | Kennya Beatriz Siqueira | EMBRAPA-CNPGL |
| 4 | Lorildo Aldo Stock | EMBRAPA-CNPGL |
| 5 | Glauco Rodrigues Carvalho | EMBRAPA-CNPGL |
| 6 | Jefferson Farias | Independent Consultancy |
| 7 | Jelson | Lactalis |
| 8 | Pablo Nepomuceno Lopes | Lactalis |
| 9 | Rejane Nunes Figueiró | Lactalis |
| 10 | Matheus Teixeira | Labor Rural |
| 11 | Christiano Nascif | Labor Rural |
| 12 | Marcelo Carvalho de Souza | Labor Rural |
| 13 | Thiago Camacho | PDPL-UFV |
| 14 | Adriano Provesano Gomes | Federal University of Viçosa (UFV) |
| 15 | Marcelo Pereira de Carvalho | Milk Point |

Table B2 - Own-price elasticities of Brazilian dairy products from specialized literature.

| | Fluid milk | Powder milk | Butter | Cheese |
|--------------------------|------------|-------------|--------|---------|
| Coelho et al. (2010) | -1.29 | -0.81 | 0.402* | -1.283 |
| Barbosa et al. (2014) | -1.501 | -1.307 | -0.419 | -1.164 |
| Coelho and Aguiar (2007) | -1.253 | -0.805 | 0.381* | -1.3415 |
| Menezes et al. (2008) | -1.24 | - | - | - |
| Alves et al. (2007) | -1.102 | -1.139 | -1.28 | - |

* Data inconsistency – author recognize estimation limitations.

APPENDIX - C

Table C1 - Seasonal milk production per cow, ration consumption of the non-adopter and adopter farms in the <50 liters per day size category.

| Month | Non-adopters | | | Adopters | | |
|----------------|-----------------------------|---------------------------------|------------------------|-----------------------------|---------------------------------|------------------------|
| | Milk production (L/cow/day) | Ration consumption (Kg/cow/day) | Ration/Milk (Kg/Liter) | Milk production (L/cow/day) | Ration consumption (Kg/cow/day) | Ration/Milk (Kg/Liter) |
| Jan | 6.03 | - | - | 7.50 | 1.00 | 0.133 |
| Feb | 5.17 | - | - | 6.90 | 1.00 | 0.145 |
| Ma | 5.60 | - | - | 6.60 | 1.00 | 0.152 |
| Apr | 3.66 | 1.00 | 0.273 | 5.40 | 1.00 | 0.185 |
| May | 3.02 | 1.00 | 0.331 | 4.80 | 1.00 | 0.208 |
| Jun | 2.59 | 1.00 | 0.387 | 4.50 | 1.00 | 0.222 |
| Jul | 2.37 | 1.00 | 0.422 | 4.20 | 1.00 | 0.238 |
| Aug | 2.37 | 1.00 | 0.422 | 4.20 | 1.00 | 0.238 |
| Sep | 2.80 | 1.00 | 0.357 | 4.80 | 1.00 | 0.208 |
| Oct | 3.66 | - | - | 5.70 | 1.00 | 0.175 |
| Nov | 4.96 | - | - | 6.72 | 1.00 | 0.149 |
| Dec | 6.25 | - | - | 7.80 | 1.00 | 0.128 |
| Average | | | 0.183 | | | 0.182 |

Table C2 - Seasonal milk production per cow, ration consumption of non-adopter and adopter farms in the 51-200 liters per day size category.

| Month | Non-adopters | | | Adopters | | |
|----------------|-----------------------------|---------------------------------|------------------------|-----------------------------|---------------------------------|------------------------|
| | Milk production (L/cow/day) | Ration consumption (Kg/cow/day) | Ration/Milk (Kg/Liter) | Milk production (L/cow/day) | Ration consumption (Kg/cow/day) | Ration/Milk (Kg/Liter) |
| Jan | 7.92 | 1.00 | 0.126 | 12.00 | 1.00 | 0.083 |
| Feb | 7.31 | 1.00 | 0.137 | 11.00 | 2.00 | 0.182 |
| Ma | 7.61 | 1.00 | 0.131 | 10.50 | 2.00 | 0.190 |
| Apr | 5.36 | 2.00 | 0.373 | 9.00 | 3.00 | 0.333 |
| May | 4.87 | 2.00 | 0.411 | 8.50 | 3.00 | 0.353 |
| Jun | 4.26 | 2.00 | 0.469 | 8.00 | 3.00 | 0.375 |
| Jul | 3.96 | 2.00 | 0.505 | 7.50 | 3.00 | 0.400 |
| Aug | 3.96 | 2.00 | 0.505 | 7.50 | 3.00 | 0.400 |
| Sep | 4.57 | 2.00 | 0.438 | 8.20 | 3.00 | 0.366 |
| Oct | 5.18 | 1.00 | 0.193 | 9.50 | 2.00 | 0.211 |
| Nov | 7.00 | 1.00 | 0.143 | 11.20 | 3.00 | 0.268 |
| Dec | 8.22 | 1.00 | 0.122 | 12.50 | 3.00 | 0.240 |
| Average | | | 0.296 | | | 0.283 |

Table C3 - Seasonal milk production per cow, ration consumption of non-adopter and adopter farms in the 201-500 liters per day size category.

| Month | Non-adopters | | | Adopters | | |
|----------------|-----------------------------|---------------------------------|------------------------|-----------------------------|---------------------------------|------------------------|
| | Milk production (L/cow/day) | Ration consumption (Kg/cow/day) | Ration/Milk (Kg/Liter) | Milk production (L/cow/day) | Ration consumption (Kg/cow/day) | Ration/Milk (Kg/Liter) |
| Jan | 9.88 | 2.00 | 0.203 | 14.38 | 4.00 | 0.278 |
| Feb | 9.05 | 2.00 | 0.221 | 13.75 | 3.00 | 0.218 |
| Ma | 9.22 | 2.00 | 0.217 | 13.13 | 3.00 | 0.229 |
| Apr | 7.41 | 3.00 | 0.405 | 11.88 | 3.00 | 0.253 |
| May | 7.00 | 3.00 | 0.429 | 10.63 | 3.00 | 0.282 |
| Jun | 6.58 | 3.00 | 0.456 | 10.25 | 3.00 | 0.293 |
| Jul | 6.17 | 3.00 | 0.486 | 10.00 | 3.00 | 0.300 |
| Aug | 6.17 | 3.00 | 0.486 | 10.00 | 3.00 | 0.300 |
| Sep | 6.75 | 3.00 | 0.445 | 10.88 | 3.00 | 0.276 |
| Oct | 7.82 | 2.00 | 0.256 | 12.50 | 3.00 | 0.240 |
| Nov | 9.22 | 2.00 | 0.217 | 14.00 | 3.00 | 0.214 |
| Dec | 10.29 | 2.00 | 0.194 | 15.00 | 4.00 | 0.267 |
| Average | | | 0.334 | | | 0.262 |

Table C4 - Seasonal milk production per cow, ration consumption of non-adopter and adopter farms in the 501-1000 liters per day size-category.

| Month | Non-adopters | | | Adopters | | |
|----------------|-----------------------------|---------------------------------|------------------------|-----------------------------|---------------------------------|------------------------|
| | Milk production (L/cow/day) | Ration consumption (Kg/cow/day) | Ration/Milk (Kg/Liter) | Milk production (L/cow/day) | Ration consumption (Kg/cow/day) | Ration/Milk (Kg/Liter) |
| Jan | 11.53 | 3.00 | 0.260 | 16.50 | 4.00 | 0.242 |
| Feb | 11.00 | 3.00 | 0.273 | 15.75 | 4.00 | 0.254 |
| Ma | 11.53 | 3.00 | 0.260 | 15.30 | 4.00 | 0.261 |
| Apr | 10.48 | 4.00 | 0.382 | 14.55 | 5.00 | 0.344 |
| May | 9.43 | 4.00 | 0.424 | 13.80 | 4.00 | 0.290 |
| Jun | 8.91 | 4.00 | 0.449 | 13.05 | 4.00 | 0.307 |
| Jul | 8.38 | 4.00 | 0.477 | 12.75 | 4.00 | 0.314 |
| Aug | 8.38 | 4.00 | 0.477 | 12.75 | 4.00 | 0.314 |
| Sep | 9.43 | 4.00 | 0.424 | 13.80 | 4.00 | 0.290 |
| Oct | 10.48 | 3.00 | 0.286 | 15.30 | 3.00 | 0.196 |
| Nov | 11.74 | 3.00 | 0.256 | 16.50 | 3.00 | 0.182 |
| Dec | 12.58 | 3.00 | 0.239 | 17.25 | 3.00 | 0.174 |
| Average | | | 0.351 | | | 0.264 |

Table C5 - Seasonal milk production per cow, ration consumption of non-adopter and adopter farms in the >1000 liters per day size-category.

| Month | Non-adopters | | | Adopters | | |
|----------------|-----------------------------|---------------------------------|------------------------|-----------------------------|---------------------------------|------------------------|
| | Milk production (L/cow/day) | Ration consumption (Kg/cow/day) | Ration/Milk (Kg/Liter) | Milk production (L/cow/day) | Ration consumption (Kg/cow/day) | Ration/Milk (Kg/Liter) |
| Jan | 14.92 | 4.00 | 0.268 | 20.70 | 5.00 | 0.242 |
| Feb | 13.89 | 4.00 | 0.288 | 19.44 | 5.00 | 0.257 |
| Ma | 13.76 | 4.00 | 0.291 | 19.26 | 5.00 | 0.260 |
| Apr | 13.50 | 5.00 | 0.370 | 18.90 | 6.00 | 0.317 |
| May | 12.60 | 5.00 | 0.397 | 17.64 | 6.00 | 0.340 |
| Jun | 11.57 | 5.00 | 0.432 | 16.20 | 5.00 | 0.309 |
| Jul | 10.80 | 5.00 | 0.463 | 15.84 | 5.00 | 0.316 |
| Aug | 11.19 | 5.00 | 0.447 | 16.20 | 5.00 | 0.309 |
| Sep | 12.22 | 5.00 | 0.409 | 17.10 | 6.00 | 0.351 |
| Oct | 13.50 | 4.00 | 0.296 | 18.90 | 5.00 | 0.265 |
| Nov | 14.15 | 4.00 | 0.283 | 19.80 | 5.00 | 0.253 |
| Dec | 14.92 | 4.00 | 0.268 | 20.70 | 5.00 | 0.242 |
| Average | 13.09 | | 0.351 | | | 0.288 |

APPENDIX - D

Table D1 – Technological parameters and economic assessment of the < 50 liters per day category for Non-adopters and Adopters.

| Description | Units | Non-adopters | Adopters |
|---------------------------------|-----------------|--------------|----------|
| Farms | % | 44.0% | |
| Production share | % | 8.2% | |
| Area | ha/farm | 24.90 | 24.90 |
| Area (pasture) | ha/farm | 23.00 | 20.64 |
| Area (sugar cane) | ha/farm | 0.70 | 2.16 |
| Area (suplm. Grass) | ha/farm | 0.70 | 2.10 |
| Area (silage) | ha/farm | 0.50 | - |
| Cow Genetics (HZ and H) | % of cows | 58.00 | 70.00 |
| Cow Genetics (Z and NDB) | % of cows | 42.00 | 30.00 |
| Artificial Insemination | % farms | 11.80 | 50.00 |
| Cow productivity | L/cow/day | 4.31 | 6.00 |
| Seasonality* | Fraction | 0.45 | 0.30 |
| Peak production (summer) | L/cow/day | 6.25 | 7.80 |
| Lower production (winter) | L/cow/day | 2.37 | 4.20 |
| Cows in milk | head | 8.00 | 9.75 |
| Total cows | head | 13.00 | 13.00 |
| Total herd | head | 42.00 | 42.00 |
| Cows in milk as % of total cows | % | 61.50 | 75.00 |
| Calving interval | Months | 13.00 | 12.67 |
| Lactation period | months | 8.00 | 9.50 |
| Milk production per day | Liter/day/farm | 34.48 | 48.00 |
| Milk production per year | Liter/year/farm | 12,585 | 21,352 |

* Seasonality = $[(\text{Max}/\text{Avg.}) - 1]$ OR $[(\text{Min}/\text{Avg.}) - 1]$

Table D2 – Economic assessment of the < 50 liters per day category for Non-adopters and Adopters.

| Description | Units per year | Non-adopters | | | Adopters | | |
|--|-------------------|-------------------|-----------------|--------------|-------------------|------------------|--------------|
| | | Dairy Activity | Milk Prod. | RS/L | Dairy activity | Milk Prod. | RS/L |
| Milk sold | R\$ | 6,019.00 | 6,019.00 | | 10,212.05 | 10,212.05 | |
| Animals sold | R\$ | 2,250.00 | | | 3,817.43 | | |
| Total Gross Revenue | R\$ | 8,269.00 | 6,019.00 | 0.48 | 14,029.48 | 10,212.05 | 0.48 |
| Labor | R\$ | 314.00 | 228.56 | 0.018 | 314.00 | 228.56 | 0.011 |
| Pasture maintenance | R\$ | 156.00 | 113.55 | 0.009 | 317.80 | 231.32 | 0.011 |
| Sugar cane maintenance | R\$ | 34.00 | 24.75 | 0.002 | 157.37 | 114.55 | 0.005 |
| Supplementary grass maintenance | R\$ | 17.00 | 12.37 | 0.001 | 102.00 | 74.25 | 0.003 |
| Silage | R\$ | 385.00 | 280.24 | 0.022 | - | - | - |
| Ration | R\$ | 1,103.00 | 802.87 | 0.064 | 2,024.07 | 1,473.32 | 0.069 |
| Minerals | R\$ | 342.00 | 248.94 | 0.020 | 627.59 | 456.82 | 0.021 |
| Artificial milk feeding | R\$ | 13.00 | 9.46 | 0.001 | 205.97 | 149.92 | 0.007 |
| Medicaments | R\$ | 422.00 | 307.17 | 0.024 | 514.31 | 374.37 | 0.018 |
| Dairy machine maintenance | R\$ | 9.00 | 6.55 | 0.001 | 15.27 | 11.11 | 0.001 |
| Transport | R\$ | 210.00 | 152.86 | 0.012 | 356.29 | 259.35 | 0.012 |
| Energy and gas | R\$ | 470.00 | 342.11 | 0.027 | 398.71 | 290.22 | 0.014 |
| Artificial Insemination | R\$ | 10.00 | 7.28 | 0.001 | 293.34 | 213.53 | 0.010 |
| Taxes | R\$ | 188.00 | 136.85 | 0.011 | 318.97 | 232.18 | 0.011 |
| Mech. and build maintenance | R\$ | 366.00 | 266.41 | 0.021 | 620.97 | 452.00 | 0.021 |
| Other | R\$ | 105.00 | 76.43 | 0.006 | 178.15 | 129.67 | 0.006 |
| Effective operational cost | R\$ | 4,144.00 | 3,016.42 | 0.240 | 6,444.81 | 4,691.18 | 0.220 |
| Family labor | R\$ | 2,671.00 | 1,944.22 | 0.154 | 2,671.00 | 1,944.22 | 0.091 |
| Depreciation | R\$ | 2,249.00 | 1,637.05 | 0.130 | 2,249.00 | 1,637.05 | 0.077 |
| Total Operational Cost | R\$ | 9,064.00 | 6,597.68 | 0.524 | 11,364.81 | 8,272.44 | 0.387 |
| Opportunity cost * | R\$ | 2,416.00 | 1,758.60 | 0.140 | 2,416.00 | 1,758.60 | 0.082 |
| Total Cost | R\$ | 11,480.00 | 8,356.28 | 0.664 | 13,780.81 | 10,031.05 | 0.470 |
| Economic indicators | | | | | | | |
| Milk as % of total revenue | % | 0.73 | | | 0.73 | | |
| Milk Gross Margin | R\$ | 4,125.00 | | | 7,584.67 | | |
| Milk Gross Margin per Liter | R\$/L | 0.33 | | | 0.43 | | |
| Milk Net Margin | R\$ | -795.00 | | | 2,664.67 | | |
| Milk Net Margin per Liter | R\$/L | -0.06 | | | 0.15 | | |
| Milk Profit | R\$ | -3,211.00 | | | 248.67 | | |
| Milk Profit per Liter | R\$/L | -0.26 | | | 0.01 | | |
| Replacement cost | R\$ | 3,123.72 | | | 3,749.77 | | |
| Replacement cost as % of gross revenue | % | 0.38 | | | 0.27 | | |

* Calculated applying the savings interest rate (6% per year) over the average immobilized capital on buildings and machinery.

Table D3 – Technological parameters of the 51-200 liters per day category for Non-adopters and Adopters.

| Description | Units | Non-adopters | Adopters |
|---------------------------------|-----------------|---------------------|-----------------|
| Farms | % | 35.4% | |
| Production share | % | 23.5% | |
| Area | ha/farm | 53.20 | 53.20 |
| Area (pasture) | ha/farm | 49.00 | 45.02 |
| Area (sugar cane) | ha/farm | 1.30 | 2.93 |
| Area (suplm. Grass) | ha/farm | 1.20 | 2.20 |
| Area (silage) | ha/farm | 1.70 | 3.04 |
| Cow Genetics (HZ and H) | % of cows | 67.00 | 75.00 |
| Cow Genetics (Z and NDB) | % of cows | 33.00 | 25.00 |
| Artificial Insemination | % farms | 11.30 | 70.00 |
| Cow productivity | L/cow/day | 6.09 | 10.00 |
| Seasonality* | Fraction | 0.35 | 0.25 |
| Peak production (summer) | L/cow/day | 8.22 | 12.50 |
| Lower production (winter) | L/cow/day | 3.96 | 7.50 |
| Cows in milk | head | 20.00 | 23.50 |
| Total cows | head | 31.00 | 31.00 |
| Total herd | head | 88.00 | 88.00 |
| Cows in milk as % of total cows | % | 64.52 | 75.00 |
| Calving interval | Months | 14.00 | 12.67 |
| Lactation period | months | 9.00 | 9.50 |
| Milk production per day | Liter/day/farm | 121.80 | 232.50 |
| Milk production per year | Liter/year/farm | 44,457.00 | 84,862.50 |

Table D4 – Economic assessment of the 51-200 liters per day category of Non-adopters and Adopters.

| Description | Units per year | Non-adopters | | | Adopters | | |
|--|-------------------|-------------------|------------------|--------------|-------------------|------------------|--------------|
| | | Dairy Activity | Milk Prod. | RS/L | Dairy activity | Milk Prod. | RS/L |
| Milk sold | R\$ | 20,960.00 | 20,960.00 | | 40,009.85 | 40,009.85 | |
| Animals sold | R\$ | 6,493.00 | | | 12,394.27 | | |
| Total Gross Revenue | R\$ | 27,453.00 | 20,960.00 | 0.471 | 52,404.13 | 40,009.85 | 0.47 |
| Labor | R\$ | 2,292.00 | 1,749.91 | 0.039 | 2,292.00 | 1,749.91 | 0.021 |
| Pasture maintenance | R\$ | 559.00 | 426.79 | 0.010 | 1,151.74 | 879.34 | 0.010 |
| Sugar cane maintenance | R\$ | 147.00 | 112.23 | 0.003 | 397.77 | 303.69 | 0.004 |
| Supplementary grass maintenance | R\$ | 80.00 | 61.08 | 0.001 | 220.00 | 167.97 | 0.002 |
| Silage | R\$ | 1,607.00 | 1,226.92 | 0.028 | 3,740.27 | 2,855.65 | 0.034 |
| Ration | R\$ | 4,952.00 | 3,780.79 | 0.085 | 12,004.34 | 9,165.15 | 0.108 |
| Minerals | R\$ | 920.00 | 702.41 | 0.016 | 2,230.21 | 1,702.73 | 0.020 |
| Artificial milk feeding | R\$ | 161.00 | 122.92 | 0.003 | 767.37 | 585.87 | 0.007 |
| Medicaments | R\$ | 1,009.00 | 770.36 | 0.017 | 1,009.00 | 770.36 | 0.009 |
| Dairy machine maintenance | R\$ | 73.00 | 55.73 | 0.001 | 139.35 | 106.39 | 0.001 |
| Transport | R\$ | 837.00 | 639.04 | 0.014 | 1,597.72 | 1,219.84 | 0.014 |
| Energy and gas | R\$ | 1,300.00 | 992.53 | 0.022 | 1,240.76 | 947.31 | 0.011 |
| Artificial Insemination | R\$ | 92.00 | 70.24 | 0.002 | 1,111.51 | 848.63 | 0.010 |
| Taxes | R\$ | 683.00 | 521.46 | 0.012 | 1,303.76 | 995.40 | 0.012 |
| Mech. and build maintenance | R\$ | 829.00 | 632.93 | 0.014 | 1,582.45 | 1,208.18 | 0.014 |
| Other | R\$ | 553.00 | 422.21 | 0.009 | 1,055.60 | 805.94 | 0.009 |
| Effective operational cost | R\$ | 16,094.00 | 12,287.55 | 0.276 | 31,843.85 | 24,312.35 | 0.286 |
| | | | | - | | | |
| Family labor | R\$ | 4,202.00 | 3,208.17 | 0.072 | 4,202.00 | 3,208.17 | 0.038 |
| Depreciation | R\$ | 5,043.00 | 3,850.26 | 0.087 | 5,043.00 | 3,850.26 | 0.045 |
| Total Operational Cost | R\$ | 25,339.00 | 19,345.99 | 0.435 | 41,088.85 | 31,370.79 | 0.370 |
| Opportunity cost | R\$ | 5,992.00 | 4,361.57 | 0.098 | 5,992.00 | 4,574.81 | 0.054 |
| Total Cost | R\$ | 31,331.00 | 23,707.56 | 0.533 | 47,080.85 | 35,945.60 | 0.424 |
| Economic indicators | | | | | | | |
| Milk as % of total revenue | % | 0.76 | | | 0.76 | | |
| Milk Gross Margin | R\$ | 11,359.00 | | | 20,560.28 | | |
| Milk Gross Margin per Liter | RS/L | 0.26 | | | 0.24 | | |
| Milk Net Margin | R\$ | 2,114.00 | | | 11,315.28 | | |
| Milk Net Margin per Liter | RS/L | 0.05 | | | 0.13 | | |
| Milk Profit | R\$ | -3,878.00 | | | 5,323.28 | | |
| Milk Profit per Liter | RS/L | -0.09 | | | 0.06 | | |
| Replacement cost | R\$ | 7,623.44 | | | 11,135.25 | | |
| Replacement cost as % of gross revenue | % | 0.28 | | | 0.21 | | |

Table D5 – Technological parameters of the 201-500 liters per day category for Non-adopters and Adopters.

| Description | Units | Non-adopters | Adopters |
|---------------------------------|-----------------|---------------------|-----------------|
| Farms | % | 14.0% | |
| Production share | % | 23.95% | |
| Area | ha/farm | 86.70 | 86.70 |
| Area (pasture) | ha/farm | 78.00 | 73.00 |
| Area (sugar cane) | ha/farm | 2.20 | 4.73 |
| Area (suplm. Grass) | ha/farm | 1.20 | 3.75 |
| Area (silage) | ha/farm | 5.30 | 5.22 |
| Cow Genetics (HZ and H) | % of cows | 71.00 | 80.00 |
| Cow Genetics (Z and NDB) | % of cows | 29.00 | 20.00 |
| Artificial Insemination | % farms | 17.10 | 80.00 |
| Cow productivity | L/cow/day | 8.23 | 12.50 |
| Seasonality* | Fraction | 0.25 | 0.20 |
| Peak production (summer) | L/cow/day | 10.29 | 15.00 |
| Lower production (winter) | L/cow/day | 6.17 | 10.00 |
| Cows in milk | head | 38.00 | 43.50 |
| Total cows | head | 58.00 | 58.00 |
| Total herd | head | 150.00 | 150.00 |
| Cows in milk as % of total cows | % | 65.52 | 75.00 |
| Calving interval | Months | 13.74 | 12.67 |
| Lactation period | months | 9.00 | 9.50 |
| Milk production per day | Liter/day/farm | 312.74 | 543.75 |
| Milk production per year | Liter/year/farm | 114,150 | 198,468 |

Table D6– Economic assessment of the 201-500 liters per day category for Non-adopters and Adopters.

| Description | Units per year | Non-adopters | | | Adopters | | |
|-----------------------------------|-------------------|-------------------|------------------|--------------|-------------------|-------------------|--------------|
| | | Dairy Activity | Milk Prod. | RS/L | Dairy activity | Milk Prod. | RS/L |
| Milk sold | R\$ | 59,226.00 | 59,226.00 | | 102,974.16 | 102,974.16 | |
| Animals sold | R\$ | 13,907.00 | | | 24,179.61 | | |
| Total Gross Revenue | R\$ | 73,133.00 | 59,226.00 | 0.519 | 127,153.77 | 102,974.16 | 0.52 |
| Labor | R\$ | 7,077.00 | 5,731.23 | 0.050 | 7,077.00 | 5,731.23 | 0.029 |
| Pasture maintenance | R\$ | 1,350.00 | 1,093.28 | 0.010 | 2,753.19 | 2,229.64 | 0.011 |
| Sugar cane maintenance | R\$ | 300.00 | 242.95 | 0.002 | 774.23 | 627.01 | 0.003 |
| Supplementary grass maintenance | R\$ | 76.00 | 61.55 | 0.001 | 296.88 | 240.42 | 0.001 |
| Silage | R\$ | 4,583.00 | 3,711.49 | 0.033 | 5,416.59 | 4,386.57 | 0.022 |
| Ration | R\$ | 15,309.00 | 12,397.83 | 0.109 | 24,507.17 | 19,846.88 | 0.100 |
| Minerals | R\$ | 2,188.00 | 1,771.93 | 0.016 | 3,502.62 | 2,836.56 | 0.014 |
| Artificial milk feeding | R\$ | 668.00 | 540.97 | 0.005 | 1,452.90 | 1,176.62 | 0.006 |
| Medicaments | R\$ | 2,382.00 | 1,929.04 | 0.017 | 2,382.00 | 1,929.04 | 0.010 |
| Dairy machine maintenance | R\$ | 385.00 | 311.79 | 0.003 | 669.39 | 542.10 | 0.003 |
| Transport | R\$ | 2,192.00 | 1,775.17 | 0.016 | 3,811.15 | 3,086.42 | 0.016 |
| Energy and gas | R\$ | 3,582.00 | 2,900.85 | 0.025 | 3,113.95 | 2,521.80 | 0.013 |
| Artificial Insemination | R\$ | 352.00 | 285.06 | 0.002 | 2,450.72 | 1,984.69 | 0.010 |
| Taxes | R\$ | 1,988.00 | 1,609.96 | 0.014 | 3,456.47 | 2,799.18 | 0.014 |
| Mech. and build maintenance | R\$ | 1,953.00 | 1,581.62 | 0.014 | 3,395.61 | 2,749.90 | 0.014 |
| Other | R\$ | 1,144.00 | 926.46 | 0.008 | 1,989.03 | 1,610.80 | 0.008 |
| Effective operational cost | R\$ | 45,529.00 | 36,871.19 | 0.323 | 67,048.89 | 54,298.84 | 0.274 |
| | | | | - | | | |
| Family labor | R\$ | 6,734.00 | 5,453.46 | 0.048 | 6,734.00 | 5,453.46 | 0.027 |
| Depreciation | R\$ | 9,725.00 | 7,875.69 | 0.069 | 9,725.00 | 7,875.69 | 0.040 |
| Total Operational Cost | R\$ | 61,988.00 | 50,200.34 | 0.440 | 83,507.89 | 67,628.00 | 0.341 |
| | | | | - | | | |
| Opportunity cost | R\$ | 11,812.00 | 8,597.95 | 0.075 | 11,812.00 | 9,565.83 | 0.048 |
| Total Cost | R\$ | 73,800.00 | 58,798.29 | 0.515 | 95,319.89 | 77,193.82 | 0.389 |
| Economic indicators | | | | | | | |
| Milk as % of total revenue | % | 0.81 | | | 0.81 | | |
| Milk Gross Margin | R\$ | 27,604.00 | | | 60,104.88 | | |
| Milk Gross Margin per Liter | R\$/L | 0.24 | | | 0.30 | | |
| Milk Net Margin | R\$ | 11,145.00 | | | 43,645.88 | | |
| Milk Net Margin per Liter | R\$/L | 0.10 | | | 0.22 | | |
| Milk Profit | R\$ | -667.00 | | | 31,833.88 | | |
| Milk Profit per Liter | R\$/L | -0.01 | | | 0.16 | | |
| Replacement cost | R\$ | 15,001.71 | | | 18,126.07 | | |
| Repl. cost as % of gross revenue | % | 0.21 | | | 0.143 | | |

Table D7 – Technological parameters of the 501-1000 liters per day category for Non-adopters and Adopters.

| Description | Units | Non-adopters | Adopters |
|---------------------------------|-----------------|---------------------|-----------------|
| Farms | % | 4.0% | |
| Production share | % | 15.1% | |
| Area | ha/farm | 122.13 | 122.13 |
| Area (pasture) | ha/farm | 104.00 | 97.96 |
| Area (sugar cane) | ha/farm | 2.77 | 4.10 |
| Area (supply. Grass) | ha/farm | 2.06 | 4.29 |
| Area (silage) | ha/farm | 13.30 | 15.78 |
| Cow Genetics (HZ and H) | % of cows | 83.00 | 90.00 |
| Cow Genetics (Z and NDB) | % of cows | 17.00 | 10.00 |
| Artificial Insemination | % farms | 17.50 | 90.00 |
| Cow productivity | L/cow/day | 10.48 | 15.00 |
| Seasonality* | Fraction | 0.20 | 0.15 |
| Peak production (summer) | L/cow/day | 12.58 | 17.25 |
| Lower production (winter) | L/cow/day | 8.38 | 12.75 |
| Cows in milk | head | 67.00 | 74.69 |
| Total cows | head | 97.00 | 144.63 |
| Total herd | head | 250.00 | 250.00 |
| Cows in milk as % of total cows | % | 69.07 | 77.00 |
| Calving interval | Months | 13.75 | 12.34 |
| Lactation period | months | 9.50 | 9.50 |
| Milk production per day | Liter/day/farm | 702.16 | 1,120.35 |
| Milk production per year | Liter/year/farm | 256,288 | 408,927.75 |

Table D8 – Economic assessment of the 501-1000 liters per day category for Non-adopters and Adopters.

| Description | Units per year | Non-adopters | | | Adopters | | |
|-----------------------------------|----------------|-------------------|-------------------|--------------|-------------------|-------------------|--------------|
| | | Dairy Activity | Milk Prod. | RS/L | Dairy activity | Milk Prod. | RS/L |
| Milk sold | R\$ | 137,868.00 | 137,868.00 | | 219,978.94 | 219,978.94 | |
| Animals sold | R\$ | 25,877.00 | | | 41,288.73 | | |
| Total Gross Revenue | R\$ | 163,745.00 | 137,868.00 | 0.538 | 261,267.68 | 219,978.94 | 0.538 |
| Labor | R\$ | 18,227.00 | 15,346.55 | 0.060 | 18,227.00 | 15,346.55 | 0.038 |
| Pasture maintenance | R\$ | 2,506.00 | 2,109.97 | 0.008 | 5,224.14 | 4,398.56 | 0.011 |
| Sugar cane maintenance | R\$ | 315.00 | 265.22 | 0.001 | 535.95 | 451.25 | 0.001 |
| Supplementary grass maintenance | R\$ | 206.00 | 173.45 | 0.001 | 492.86 | 414.97 | 0.001 |
| Silage | R\$ | 11,712.00 | 9,861.13 | 0.038 | 16,677.04 | 14,041.53 | 0.034 |
| Ration | R\$ | 36,604.00 | 30,819.39 | 0.120 | 49,053.79 | 41,301.70 | 0.101 |
| Minerals | R\$ | 4,386.00 | 3,692.87 | 0.014 | 5,877.77 | 4,948.89 | 0.012 |
| Artificial milk feeding | R\$ | 2,099.00 | 1,767.29 | 0.007 | 3,041.89 | 2,561.17 | 0.006 |
| Medicaments | R\$ | 5,269.00 | 4,436.33 | 0.017 | 5,269.00 | 4,436.33 | 0.011 |
| Dairy machine maintenance | R\$ | 1,603.00 | 1,349.67 | 0.005 | 2,557.71 | 2,153.51 | 0.005 |
| Transport | R\$ | 3,914.00 | 3,295.46 | 0.013 | 6,245.09 | 5,258.16 | 0.013 |
| Energy and gas | R\$ | 9,473.00 | 7,975.96 | 0.031 | 7,557.45 | 6,363.13 | 0.016 |
| Artificial Insemination | R\$ | 683.00 | 575.06 | 0.002 | 7,285.22 | 6,133.92 | 0.015 |
| Taxes | R\$ | 5,417.00 | 4,560.94 | 0.018 | 8,643.24 | 7,277.33 | 0.018 |
| Mech. and build maintenance | R\$ | 4,428.00 | 3,728.23 | 0.015 | 7,065.21 | 5,948.68 | 0.015 |
| Other | R\$ | 1,810.00 | 1,523.96 | 0.006 | 2,887.99 | 2,431.60 | 0.006 |
| Effective operational cost | R\$ | 108,652.00 | 91,481.47 | 0.357 | 146,641.34 | 123,467.27 | 0.302 |
| Family labor | R\$ | 7,920.00 | 6,668.38 | 0.026 | 7,920.00 | 6,668.38 | 0.016 |
| Depreciation | R\$ | 16,029.00 | 13,495.90 | 0.053 | 16,029.00 | 13,495.90 | 0.033 |
| Total Operational Cost | R\$ | 132,601.00 | 111,645.76 | 0.436 | 170,590.34 | 143,631.55 | 0.351 |
| Opportunity cost | R\$ | 20,993.00 | 15,280.79 | 0.060 | 20,993.00 | 17,675.43 | 0.043 |
| Total Cost | R\$ | 153,594.00 | 126,926.55 | 0.495 | 191,583.34 | 161,306.98 | 0.394 |
| Economic indicators | | | | | | | |
| Milk as % of total revenue | % | 0.84 | | | 0.84 | | |
| Milk Gross Margin | R\$ | 55,093.00 | | | 114,626.34 | | |
| Milk Gross Margin per Liter | RS/L | 0.21 | | | 0.28 | | |
| Milk Net Margin | R\$ | 31,144.00 | | | 90,677.34 | | |
| Milk Net Margin per Liter | RS/L | 0.12 | | | 0.22 | | |
| Milk Profit | R\$ | 10,151.00 | | | 69,684.34 | | |
| Milk Profit per Liter | RS/L | 0.04 | | | 0.17 | | |
| Replacement cost | R\$ | 26,667.45 | | | 30,276.36 | | |
| Repl. cost as % of gross revenue | % | 0.16 | | | 0.116 | | |

Table D9 – Technological parameters of the >1,000 liters per day category for Non-adopters and Adopters.

| Description | Units | Non-adopters | Adopters |
|---------------------------------|-----------------|---------------------|-----------------|
| Farms | % | 2.6% | |
| Production share | % | 29.4% | |
| Area | ha/farm | 258.83 | 258.83 |
| Area (pasture) | ha/farm | 218.00 | 204.55 |
| Area (sugar cane) | ha/farm | 8.80 | 8.87 |
| Area (suplm. Grass) | ha/farm | 3.23 | 9.39 |
| Area (silage) | ha/farm | 28.80 | 36.02 |
| Cow Genetics (HZ and H) | % of cows | 96.00 | 90.00 |
| Cow Genetics (Z and NDB) | % of cows | 4.00 | 10.00 |
| Artificial Insemination | % farms | 23.00 | 90.00 |
| Cow productivity | L/cow/day | 12.86 | 18.00 |
| Seasonality* | Fraction | 0.16 | 0.15 |
| Peak production (summer) | L/cow/day | 14.92 | 20.70 |
| Lower production (winter) | L/cow/day | 10.80 | 15.30 |
| Cows in milk | head | 163.00 | 173.60 |
| Total cows | head | 217.00 | 217.00 |
| Total herd | head | 548.00 | 548.00 |
| Cows in milk as % of total cows | % | 75.12 | 80.00 |
| Calving interval | Months | 13.31 | 12.50 |
| Lactation period | months | 10.00 | 10.00 |
| Milk production per day | Liter/day/farm | 2,096.18 | 3,124.80 |
| Milk production per year | Liter/year/farm | 765,105 | 1,140,552 |

Table D10 – Economic assessment of the >1000 liters per day category for Non-adopters and Adopters.

| Description | Units per year | Non-adopters | | | Adopters | | |
|-----------------------------------|-------------------|-------------------|-------------------|--------------|-------------------|-------------------|--------------|
| | | Dairy Activity | Milk Prod. | RS/L | Dairy activity | Milk Prod. | RS/L |
| Milk sold | R\$ | 446,731.97 | 446,731.97 | | 665,948.56 | 665,948.56 | |
| Animals sold | R\$ | 86,784.00 | | | 129,369.92 | | |
| Total Gross Revenue | R\$ | 533,515.97 | 446,731.97 | 0.584 | 795,318.49 | 665,948.56 | 0.584 |
| Labor | R\$ | 59,668.00 | 49,962.15 | 0.065 | 59,668.00 | 49,962.15 | 0.044 |
| Pasture maintenance | R\$ | 19,407.00 | 16,250.17 | 0.021 | 39,231.24 | 32,849.72 | 0.029 |
| Sugar cane maintenance | R\$ | 2,356.00 | 1,972.76 | 0.003 | 2,729.74 | 2,285.71 | 0.002 |
| Supplementary grass maintenance | R\$ | 50.00 | 41.87 | 0.000 | 167.24 | 140.03 | 0.000 |
| Silage | R\$ | 37,604.00 | 31,487.17 | 0.041 | 54,088.89 | 45,290.56 | 0.040 |
| Ration | R\$ | 139,388.00 | 116,714.55 | 0.153 | 149,833.24 | 125,460.72 | 0.110 |
| Minerals | R\$ | 9,695.00 | 8,117.97 | 0.011 | 10,421.51 | 8,726.30 | 0.008 |
| Artificial milk feeding | R\$ | 7,800.00 | 6,531.22 | 0.009 | 8,307.24 | 6,955.95 | 0.006 |
| Medicaments | R\$ | 20,501.00 | 17,166.22 | 0.022 | 20,501.00 | 17,166.22 | 0.015 |
| Dairy machine maintenance | R\$ | 4,324.00 | 3,620.64 | 0.005 | 6,445.84 | 5,397.33 | 0.005 |
| Transport | R\$ | 7,978.00 | 6,680.26 | 0.009 | 11,892.90 | 9,958.35 | 0.009 |
| Energy and gas | R\$ | 25,567.00 | 21,408.16 | 0.028 | 19,056.51 | 15,956.70 | 0.014 |
| Artificial Insemination | R\$ | 5,539.00 | 4,638.00 | 0.006 | 20,431.81 | 17,108.28 | 0.015 |
| Taxes | R\$ | 13,230.00 | 11,077.95 | 0.014 | 19,722.12 | 16,514.03 | 0.014 |
| Mech. and build maintenance | R\$ | 15,911.00 | 13,322.85 | 0.017 | 23,718.71 | 19,860.53 | 0.017 |
| Other | R\$ | 2,086.00 | 1,746.68 | 0.002 | 3,109.62 | 2,603.80 | 0.002 |
| Effective operational cost | R\$ | 371,104.00 | 310,738.63 | 0.406 | 449,325.61 | 376,236.37 | 0.330 |
| Family labor | R\$ | 19,934.00 | 16,691.45 | 0.022 | 19,934.00 | 16,691.45 | 0.015 |
| Depreciation | R\$ | 32,030.00 | 26,819.86 | 0.035 | 32,030.00 | 26,819.86 | 0.024 |
| Total Operational Cost | R\$ | 423,068.00 | 354,249.94 | 0.463 | 501,289.61 | 419,747.68 | 0.368 |
| Opportunity cost | R\$ | 56,452.00 | 41,091.38 | 0.054 | 56,452.00 | 47,269.28 | 0.041 |
| Total Cost | R\$ | 479,520.00 | 395,341.32 | 0.517 | 557,741.61 | 467,016.96 | 0.409 |
| Economic indicators | | | | | | | |
| Milk as % of total revenue | % | 0.84 | | | 0.84 | | |
| Milk Gross Margin | R\$ | 162,411.97 | | | 345,992.88 | | |
| Milk Gross Margin per Liter | RS/L | 0.21 | | | 0.30 | | |
| Milk Net Margin | R\$ | 110,447.97 | | | 294,028.88 | | |
| Milk Net Margin per Liter | RS/L | 0.14 | | | 0.26 | | |
| Milk Profit | R\$ | 53,995.97 | | | 237,576.88 | | |
| Milk Profit per Liter | RS/L | 0.07 | | | 0.21 | | |
| Replacement cost | R\$ | 84,178.68 | | | 90,724.65 | | |
| Repl. cost as % of gross revenue | % | 0.16 | | | 0.11 | | |

APPENDIX - E

Table E1 – Wholesale price, retail price, product sale and value of retail sale of dairy products for the Baseline and six scenarios of technology adoption rate, average from January 2006 to December 2016.

| Category (unit) | Baseline | SS | SM | SF | LS | LM | LF |
|--|-----------------|-------------|-------------|-------------|-------------|-------------|-------------|
| <i>Wholesale Price (R\$/unit)</i> | | | | | | | |
| Fluid | 1.92 | 1.87 | 1.84 | 1.84 | 1.86 | 1.83 | 1.83 |
| Storable | 4.91 | 4.81 | 4.77 | 4.76 | 4.81 | 4.73 | 4.73 |
| Soft | 0.69 | 0.67 | 0.66 | 0.66 | 0.67 | 0.65 | 0.65 |
| Balancing | 10.96 | 10.70 | 9.82 | 9.55 | 10.81 | 9.96 | 9.52 |
| <i>Retail Price (R\$/unit)</i> | | | | | | | |
| Fluid | 2.32 | 2.27 | 2.25 | 2.25 | 2.27 | 2.241 | 2.241 |
| Storable | 8.24 | 8.14 | 8.10 | 8.09 | 8.14 | 8.06 | 8.06 |
| Soft | 4.36 | 4.34 | 4.33 | 4.33 | 4.34 | 4.32 | 4.32 |
| Balancing | 17.44 | 17.18 | 16.30 | 16.03 | 17.29 | 16.44 | 16.00 |
| <i>Product Sales (bil kg/year)</i> | | | | | | | |
| Fluid | 9.5 | 9.7 | 9.9 | 9.9 | 9.8 | 9.9 | 9.9 |
| Storable | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Soft | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Balancing | 1.8 | 2.0 | 2.2 | 2.3 | 2.0 | 2.4 | 2.6 |
| <i>Value of Retail Sales (bil R\$/year)</i> | | | | | | | |
| Fluid | 22.0 | 22.1 | 22.2 | 22.2 | 22.1 | 22.3 | 22.3 |
| Storable | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 |
| Soft | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Balancing | 32.1 | 34.2 | 36.3 | 36.8 | 34.5 | 39.8 | 40.8 |
| Total | 56.4 | 58.6 | 60.8 | 61.3 | 58.9 | 64.4 | 65.3 |

Table E2 – Percentage difference from the Baseline for wholesale price, retail price, product sale and value of retail sale of dairy products.

| Category (unit) | Baseline | SS | SM | SF | LS | LM | LF |
|--|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|
| <i>Difference from Baseline wholesale Price (%)</i> | | | | | | | |
| Fluid | | -2.6 | -3.7 | -3.7 | -2.8 | -4.3 | -4.3 |
| Storable | | -1.9 | -2.9 | -2.9 | -1.9 | -3.5 | -3.5 |
| Soft | | -2.6 | -3.9 | -4.1 | -2.5 | -4.8 | -4.8 |
| Balancing | | -2.4 | -10.4 | -12.9 | -1.4 | -9.1 | -13.1 |
| <i>Difference from Baseline retail Price (%)</i> | | | | | | | |
| Fluid | | -2.1 | -3.1 | -3.1 | -2.3 | -3.5 | -3.5 |
| Storable | | -1.1 | -1.7 | -1.7 | -1.1 | -2.1 | -2.1 |
| Soft | | -0.4 | -0.6 | -0.6 | -0.4 | -0.8 | -0.8 |
| Balancing | | -1.5 | -6.5 | -8.1 | -0.9 | -5.7 | -8.3 |
| <i>Difference from Baseline Product Sales (%)</i> | | | | | | | |
| Fluid | | 2.9 | 4.2 | 4.2 | 3.0 | 4.9 | 4.9 |
| Storable | | 1.6 | 2.4 | 2.5 | 1.6 | 3.0 | 3.0 |
| Soft | | 0.9 | 1.3 | 1.4 | 0.8 | 1.6 | 1.6 |
| Balancing | | 8.1 | 20.8 | 24.7 | 8.3 | 31.5 | 38.5 |
| <i>Difference from Baseline value of Retail Sales (%)</i> | | | | | | | |
| Fluid | | 0.7 | 1.0 | 1.0 | 0.6 | 1.1 | 1.1 |
| Storable | | 0.4 | 0.7 | 0.7 | 0.4 | 0.9 | 0.9 |
| Soft | | 0.5 | 0.7 | 0.7 | 0.4 | 0.9 | 0.9 |
| Balancing | | 6.5 | 12.9 | 14.7 | 7.3 | 24.0 | 27.0 |
| Total | | 4.0 | 7.8 | 8.8 | 4.5 | 14.2 | 15.9 |

Table E3 – Milk production fraction for each farm-size category for the Baseline and six scenarios of technology adoption rate at the end of simulation period.

| Category (unit) | Baseline | SS | SM | SF | LS | LM | LF |
|----------------------------|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|
| <50 Liters/day | | | | | | | |
| Non-adopters | 6.6 | 3.6 | 0.3 | 0.0 | 4.7 | 3.0 | 2.7 |
| Adopters | - | 4.4 | 10.0 | 10.8 | - | - | - |
| Sum | 6.6 | 8.1 | 10.3 | 10.8 | 4.7 | 3.0 | 2.7 |
| 51-200 Liters/day | | | | | | | |
| Non-adopters | 18.2 | 10.0 | 0.8 | 0.1 | 12.9 | 7.9 | 7.0 |
| Adopters | - | 13.5 | 29.7 | 31.7 | - | - | - |
| Sum | 18.2 | 23.5 | 30.5 | 31.7 | 12.9 | 7.9 | 7.0 |
| 201-500 Liters/day | | | | | | | |
| Non-adopters | 23.4 | 21.3 | 18.6 | 18.2 | 9.9 | 0.6 | 0.0 |
| Adopters | - | - | - | - | 17.9 | 29.9 | 30.3 |
| Sum | 23.4 | 21.3 | 18.6 | 18.2 | 27.8 | 30.5 | 30.3 |
| 501-1000 Liters/day | | | | | | | |
| Non-adopters | 17.7 | 16.1 | 13.9 | 13.4 | 7.5 | 0.5 | 0.0 |
| Adopters | - | - | - | - | 11.7 | 20.6 | 21.5 |
| Sum | 17.7 | 16.1 | 13.9 | 13.4 | 19.2 | 21.0 | 21.6 |
| >1000 Liters/day | | | | | | | |
| Non-adopters | 34.1 | 31.1 | 26.7 | 25.8 | 14.5 | 0.9 | 0.1 |
| Adopters | - | - | - | - | 20.9 | 36.8 | 38.4 |
| Sum | 34.1 | 31.1 | 26.7 | 25.8 | 35.4 | 37.7 | 38.4 |