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RESEARCH ARTICLE

Synergies and Trade-offs Between the Food Policy Objectives: Evidence from the Dairy Sector of Senegal

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Abstract

This study investigates the effects of genetic improvement policies on dairy production, with a particular emphasis on Artificial Insemination projects. Furthermore, we evaluate the major barriers and challenges of Artificial Insemination projects including water scarcity. Using the data-driven synthetic control method, we found evidence that the Artificial Insemination projects caused milk production to increase by 59 thousand tons on average from 2008 to 2018. This could be correlated with food security (i.e., synergies), but increased dairy production may also place strain on Senegal's water resources (i.e. trade-offs). To achieve a more efficient outcome, Senegalese dairy policies should consider the negative externalities of these projects on water resources.

Keywords: Artificial insemination; Food policy; Synthetic control method; Genetic improvement policy; Senegal

JEL classifications: Q11; Q18; Q32

1. Introduction

Agriculture remains the primary means of livelihood, particularly for the 8.6 million people who live in rural areas (FAOSTAT, 2019). Despite the small contribution of the agricultural sector to the overall economy, this sector employs over 60% of the total labor force in Senegal (World Bank, 2019). The dairy sector is one of the most important agricultural subsectors in Senegal because it plays a critical role in their daily cash income as well as food and nutrition security (Wolfenson, 2013). However, dairy production is insufficient to meet domestic demand, so large amounts of milk, primarily in powdered form, are imported each year (FAOSTAT, 2019)[1]. Moreover, due to a combination of unstable international powdered milk prices triggered by the global food price crisis in 2007–2008 and rapid growth of urban demand, policymakers and private dairy businesses have demonstrated a renewed interest in expanding domestic production (Magnani et al., 2019).

In terms of food security, livestock is a noted sector in Senegal. The main cause of low milk production is the low genetic potential of native cattle breeds raised (Diouf et al., 2016; Marshall et al., 2016). Climatic conditions such as water resource scarcity, extreme temperature, animal health risks, and poor feed, in terms of quality and quantity, are identified as the factors explaining the gap between the potential and actual yield of dairy products in Senegal (Duteurtre et al., 2021; Marshall et al., 2016; Niemi et al., 2016; Raile et al., 2019). Besides, the various infectious production diseases and parasites such as flies, ticks, mites, and helminths cause reduced milk production

[1]In 2018, 251 thousand tons (milk equivalent) of dairy products were produced in Senegal, while 595 thousand tons were imported.

and financial losses due to control, treatment, and mortality costs (Rashid et al., 2019; Whatford et al., 2022).

In Senegal, genetic improvement of local breeds has been considered the preferred strategy for rapidly improving milk yield and therefore reducing imports of dairy products in Senegal (Magnani et al., 2019; Seck et al., 2016). Since 2008, the major public intervention in the livestock sector in Senegal has been a national breeding plan to improve cattle genetics through Artificial Insemination projects (Magnani et al., 2015). Although empirical studies evaluating the effectiveness of these projects are limited in Senegal, the existing literature argues that the genetic improvement programs have not achieved the expected outcomes (e.g., Magnani et al., 2015). This study was undertaken to test the hypothesis that genetic improvement through Artificial Insemination projects can be seen as one of the effective strategies to increase milk yield. However, water scarcity and drought stress may hinder the actual positive effects of such interventions on the development of local dairy production.

The present analysis contributes to the literature by empirically investigating the effects of Artificial Insemination initiatives on domestic milk production and evaluating the potential synergies and trade-offs between dairy policy objectives in Senegal. The study objectives are indicated threefold. We first identify the most influential policies including genitive improvement policies in the dairy sector of Senegal from 1996 to 2018 through an extensive review of the literature. Second, we use the data-driven synthetic control method (SCM) to evaluate the impact of the identified policies. This technique estimates the policy effects on the trajectory of milk production by constructing a weighted combination of control units, which reflects what the production in Senegal would have experienced in the absence of Artificial Insemination projects. Finally, we evaluate the potential barriers to milk production and explore ways to optimize policy interventions by assessing the coherence between dairy policy objectives in Senegal. To do so, we project the possible effects of Artificial Insemination programs on the water resources using estimates of milk production. This framework allows us to shed light on the potential synergies and trade-offs between different challenges in the dairy sector of Senegal.

The remaining sections of this paper are structured as follows: Section 2 presents a general overview of the dairy sector. In Section 3, dairy policies and programs implemented over the years are explained. Section 4 describes the methods of analysis, while Section 5 summarizes the key findings.

2. Overview of the Dairy Sector in Senegal

The livestock sector comprising cattle, goats, sheep, and poultry plays a significant role in improving household income and food security for subsistence farmers and pastoralists in Senegal. Although livestock accounts for only 3.6% of the national GDP, it is an integral part of many other agricultural enterprises providing draught power, organic fertilizer, and despite accounting for only 3.6% of national GDP, livestock is an integral part of many other agricultural enterprises, providing draught power, organic fertilizer, and transportation (ANSD Senegal, 2020). Senegal's cattle population is 3.7 million head, accounting for 1% of Africa's cattle population (FAOSTAT, 2019). This comprises indigenous and exotic cattle breeds and their crossbreeds. Cattle rearing is classified under three major dairy production systems in Senegal: pastoral, agro-pastoral, and, most recently, the intensive peri-urban (confined silage) system (Figure 1).

The pastoral system is extensive farming practiced mainly in the north and the north-central regions of the country (Ferlo and the Senegal River areas). The Ferlo covers one-third of Senegal's landmass and is home to two-thirds of the country's domestic ruminants, including 15% of the cattle population. This system accounts for approximately 38% of national milk production, which is primarily exploited by the Gobra and Gouzerat cattle breeds (Seck et al., 2016). The average herd size and annual milk yield are 15 dairy cows and 179 l per cow, respectively. Despite this system's

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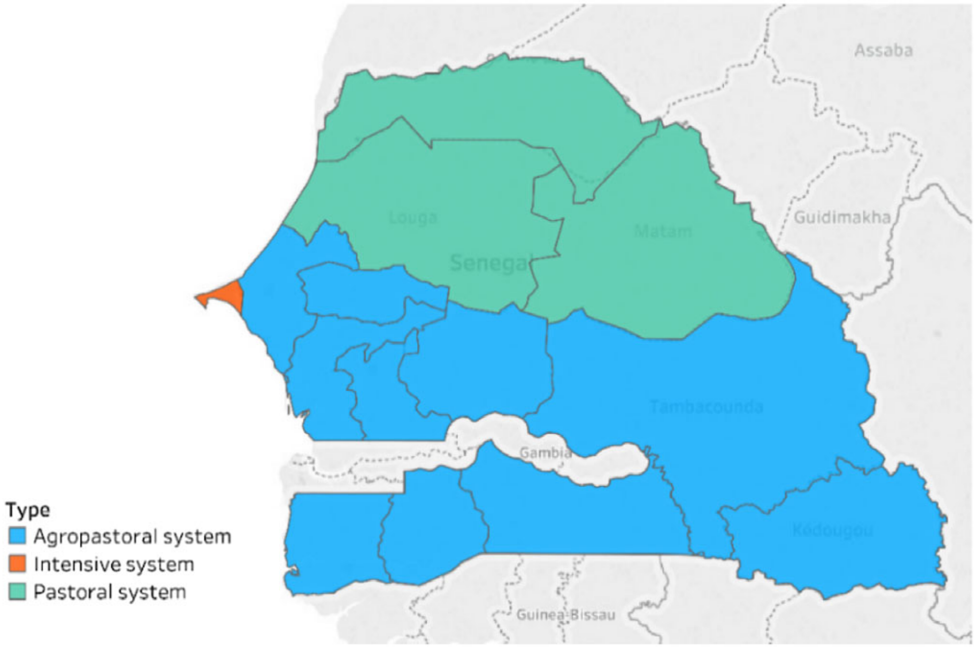

Figure 1. Location of dairy production systems in Senegal.
Source: Own presentation based on Dieye (2006).

contribution, there are production constraints such as irregular water supply, which worsens during the dry season, and insufficient veterinary coverage for farm animals. Apart from these constraints, Nestlé Senegal built a milk collection network in this zone from 1992 to 2003 because it is the only one that produces the most milk during the rainy season.

The agro-pastoral system is found in the groundnut basin/production zone (administrative regions of Diourbel, Louga, Kaolack, Thiès, and Fatick) and the south administrative regions of Kolda, Ziguinchor, and Tambacounda. Around 25% and 20% of the national cattle herd are located in the groundnut zone and the southern administrative regions, respectively (Duteurtre, 2006). In this production system, cattle are typically kept for beef production and animal traction by traditional Fulani pastoralists. Moreover, the average herd size and annual milk yield are 15 dairy cows and 600 l per cow, respectively (Gunarathne et al., 2022). Artificial Insemination first appeared in the groundnut zone in 1994 with the Livestock Support Project (PAPEL)[2], which was intended to improve the level of milk production of local cattle breeds. This project enabled the exploitation of cross-bred cows and enhanced the level of milk production (about 6 l/cow/day) and the income of the producers (Dia, 2004). Despite the performance recorded in this system, constraints to the improvement of production persist. In this production system, breeding is achieved through Artificial Insemination or natural service depending on the farmer's production goal, whether dairy or beef products. This decision on the production goal is mainly dependent on the availability of food (forage) in the dry season.

The intensive peri-urban system (confined silage) is usually practiced mainly in the Niayes area of Dakar-Thiès. It represents less than 1% of the cattle herd in Senegal and is primarily based on the use of exotic cows (Montbeliard, Jersey, Holstein, and Gir) in permanent stabling for milk production. Milk production is of the highest interest in this production system and because of that Artificial Insemination is widely applied to increase the production of milk. The average daily

[2]In French: Projet d'Appui à l'Élevage.

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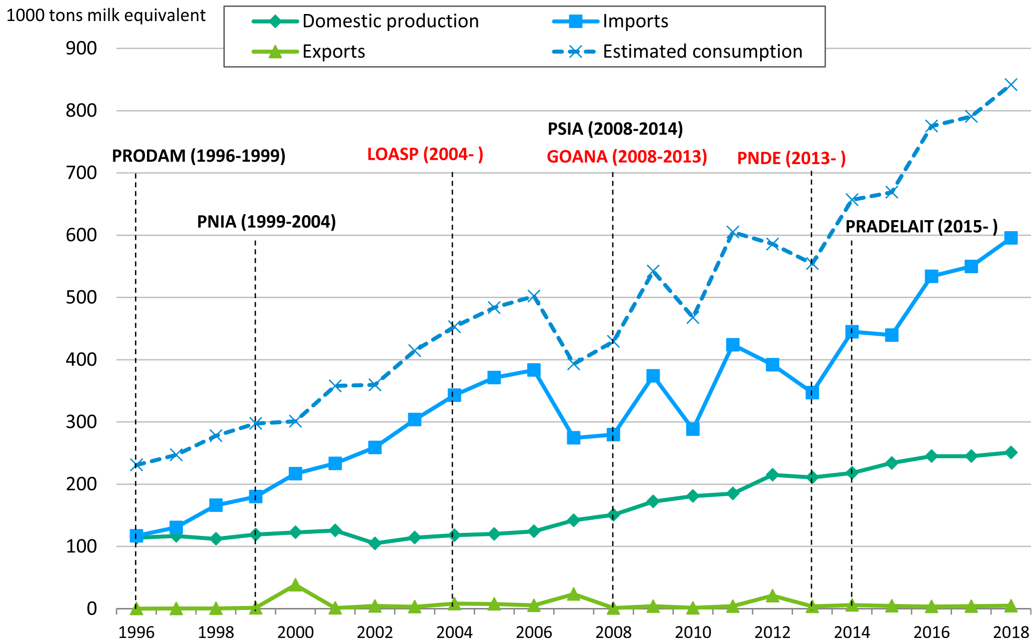

Figure 2. Development of the Dairy Sector in Senegal from 1996 to 2018 (in 1000 tons, milk equivalent). *Note*: Domestic consumption is calculated using imports plus production minus exports. Storage was not considered. Artificial Insemination projects are shown in black, while other livestock policies are shown in red. The policies are discussed in detail in the following section.
Source: Exports and imports are based on UN Comtrade (2018). the production data is retrieved from FAOSTAT (2019).

milk yield per cow is considerably high compared to the other two systems with the production of 30.0 l in the rainy season (June–October) and 15.0 l in the dry season (November–May). The average dairy farm has about 90 cows, and the annual milk yield is 3,150 l per cow (Gunarathne et al., 2022).

Due to the low quantities of milk produced in the dominant systems (pastoral and agro-pastoral), the national supply is unable to meet the growing demand for milk and dairy products. In addition to other dairy products, the country imports 100,000 metric tons of powdered milk annually, representing more than USD 400 million (Zamani et al., 2021). Moreover, in 2018, the total dairy imports amounted to about 595 million tons of milk equivalent, accounting for about 85% of the milk powder and full-fat milk by value (UN Comtrade, 2018). According to Zamani et al. (2021), the self-sufficiency rate of the Senegalese dairy sector steadily declined from 41% to 20% between 2000 and 2018 (Figure 2). This indicates that the dependency on imported milk and milk products will continue to increase in the future.

3. Dairy Policies and Programs in Senegal

The public policies in Senegal are generally formulated to make the agricultural sector a driver for economic growth and farmers' livelihood improvement (Demont and Rizzotto, 2012). After an expensive period of state intervention between the 1960s and 1980s, Senegal adopted the Structural Adjustment Programs in Agriculture in the 1980s, intended to remove too much state control in the agricultural sector. In this program, privatization and market liberalization were the main components (Resnick and Birner, 2010; Weissman, 1990).

In the dairy sector, the reduction of import dependency through increasing domestic production has been a central objective for public interventions that are jointly implemented by the

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private sector, NGOs, and public projects (Dieye et al., 2005). The dairy sector's policies cover five thematic areas including institutional policies (e.g., organization of dairy industries, farmers' associations), access to natural resources (e.g., water and land), livestock development (e.g., genetic improvement), economic and trade policies such as tariffs and non-tariff barriers, subsidies, and macroeconomic policies (Dieye et al., 2005; Seck et al., 2016).

Adopted in 2004, the Agriculture, Forestry, and Livestock Act (LOASP)[3] represents an important institutional framework for reviving the agricultural sector of Senegal. Aimed at achieving food security and increasing the income sources of farmers, this law constitutes a legal framework for implementing the agricultural development plan in Senegal for the next 20 years (FAO, 2015). This law led to the implementation of several operational plans and projects, including the National Agricultural Development Program, the National Program for Livestock Development (PNDE)[4], and the Grand Agricultural Offensive for Food and Abundance (GOANA)[5]. These programs are common in identifying livestock among the priority sectors that significantly impact the achievement of the Millennium Development Goals (Diouf et al., 2016).

As part of the LOASP, the Ministry of Livestock launched the PNDE as a framework for the implementation of interventions in the livestock sector. This plan specifically addresses animal husbandry. More specifically, it seeks to increase the productivity and competitiveness of animal value chains and to reach self-sufficiency in this market by 2026 (Seck et al., 2016; World Bank, 2020; WTO, 2017). The program became operational in 2013, and it covers five specific pillars namely; improving productivity, developing breeding systems, improving product marketing, and strengthening institutional structure (Seck et al., 2016; World Bank, 2020).

From 2000 to 2005, Senegalese dairy imports grew substantially from 23 to 42 billion CFA (35–64 million Euro) (Duteurtre, 2009). However, the 2007–2008 food price spike highlighted the high vulnerability of Senegal's food security to international food price variations (Seck et al., 2016). As a result, several contingency policies were implemented to control milk prices, such as tax exemptions for powdered milk imports. As already mentioned, GOANA, which combines technical components like animal feed, cross-breeding, and Artificial Insemination with trade-related policies like tax exemptions for production inputs and the processing of local milk, was also implemented by the government in 2008 to lessen Senegal's dependence on imported food (Demont and Rizzotto, 2012; Magnani et al., 2015). Nevertheless, due to a lack of finances, only Artificial Insemination effectively became operational under the GOANA project which finances breeding and genetic improvement (Magnani et al., 2019). Further, the GOANA got replaced by the New Alliance for Food Security and Nutrition in 2012 (FAO, 2015). The Artificial Insemination projects are discussed in the following section. Recently, in June 2018, the "my milk is local" campaign was launched in several countries in West Africa by a coalition of organizations of professionals in the dairy sector, NGOs, and research institutes. The goal of this advocacy was to encourage domestic milk consumption in milk-producing nations including Burkina Faso, Mali, Mauritania, Niger, Ghana, and Senegal (GRET, 2019). There is currently no information available to assess the effectiveness of this campaign.

3.1. Genetic Improvement Policy and Programs

In Senegal, Artificial Insemination has been widely supported by successive national programs. Subsidized by the public sector, all dairy genetic improvement programs in Senegal[6] have been

[3]In French: Loi d'Orientation Agro Sylvo Pastorale.

[4]In French: Plan National de Développement de l'Elevage.

[5]In French: Grande Offensive Agricole pour la Nourriture et l'Abondance.

[6]Except two campaigns, the other programs were used to be free of charge for farmers. This policy was recently changed, and the majority of the programs now have a cost.

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implemented at no cost to cattle keepers (Marshall et al., 2016). The main stakeholders of the genetic improvement policies include the state, livestock professionals, public services, and private companies, including veterinarians, livestock technicians, and the beneficiary dairy farmers (Diouf et al., 2016).

As laid out above, in 1992, the Livestock Support Project (PAPEL) was launched to improve the production of milk and meat in the Groundnut and Sylvopastoral zones. This project was funded by the government of Senegal with the support of the African Development Bank. In this project, around 5,000 cows located in these production zones were inseminated between 1995 and 2005. The results showed an overall 43.4% pregnancy rate per Artificial Insemination recorded for the years 1995–1998. A higher pregnancy rate (73.6%) was obtained in 1996, and the lowest rate of 38.8% was recorded in 1997. According to Seck et al. (2016), the decrease in the pregnancy rate in 1997 was most likely due to a lack of forage in that year. The PAPEL project was followed by the Agricultural Development Project in Matam (PRODAM)[7] implemented in northern Senegal. In this project, 768 cows were inseminated in two phases (1996/1997 and 1998/1999) with an average success rate of 31% and 42% recorded for the first and second campaigns, respectively (Diouf et al., 2016).

As part of the national milk production development policy, three breeding campaigns were conducted under the National Artificial Insemination Program (PNIA)[8] in 1999, 2001, and 2004. This was done predominantly by private companies using protocols based on the specifications of agroecological zones. As a result, the overall insemination success rate increased from 31% to 42% between 1999 and 2001 (Gueye, 2003; Magnani et al., 2015). However, challenges with feeding, technicians' lack of experience, and the geographical dispersion of activities were noted as some of the major obstacles that adversely affected Artificial Insemination programs. This can be observed in Figure 1, where the earlier insemination programs (including PAPEL and PNIA) resulted in little changes in domestic production from 1996 to 2004.

Later, in 2008, the GOANA program was implemented to increase livestock production through the implementation of various genetic improvement initiatives (Cabral, 2016). From 2008 to 2014, the livestock component of GOANA, known as the Special Artificial Insemination Program (PSIA)[9], operated as an autonomous genetic improvement program. The production objective of PSIA was to inseminate 500,000 cows by 2012 with the expectation of obtaining 100,000 cross-breeds and additional milk production of up to 400 million liters (Seck et al., 2016). From 2008 to 2014, 116,024 cows were artificially inseminated under this program, with a 42.5% success rate (Ministry of Livestock and Animal Production, 2012, 2014). Because of this insight, the Senegalese government proposed Artificial Insemination as the greatest technical solution for significantly raising domestic milk production and lowering imports. Due to some good progress by the government, the insemination programs were used to showcase the presidential commitment to modernity testifying to a growing "technicist" attitude in dairy development (Magnani et al., 2019, pp. 143–58). Out of the 20,000 cows that were intended to be inseminated as part of the PSIA (from 2010 to 2011), 19,209 were actually inseminated, representing 96% of the initial target. However, the evaluation of PSIA highlights a reduction in the pregnancy rate from 47.4% to 44.2% over the implementation period (Seck et al., 2016). Additionally, critics have expressed concerns over the ineffective monitoring of project outcomes, which is required for the project's evaluation.

In spite of the challenges with PSIA, the government made the decision to continue the genetic improvement plan through the Dairy Industry Development Support Project (PRADELAIT)[10]. This project was carried out within the framework of the 2014–2018 Emerging Senegalese Plan (PSE)[11]

[7]In French: Projet de Développement Agricole de Matam.
[8]In French: Programme National d'Insémination Artificielle.
[9]In French: Programme Spécial d'Insémination Artificielle.
[10]In French: Projet d'Appui au développement de la filière lait.
[11]In French: Le Plan Sénégal Emergent.

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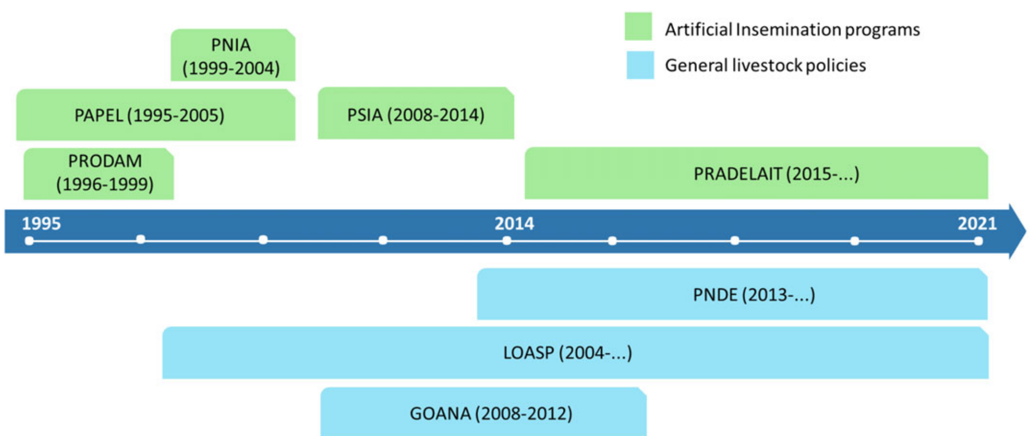

Figure 3. Timeline of different Artificial Insemination programs and livestock policies in Senegal (1995–2021). *Source*: own representation.

with a budget of 30 million euros (Diouf et al., 2016). The PRADELAIT project, like PSIA, sought to improve milk production through production systems intensification and modernization. The project's goal was to help create jobs and generate income, as well as to alleviate extreme poverty, and improve food security, especially in rural areas. Figure 3 shows the timelines of Artificial Insemination and livestock improvement projects implemented in Senegal.

4. Data and Method

4.1. Synthetic Control Method

Due to limited data availability, the empirical analysis of policy effects in developing countries is a difficult task. To overcome this challenge, some scholars have proposed the SCM (Luo and Kostandini, 2021; Olper et al., 2018). This technique has been widely used in recent years to estimate the effects of policy interventions in various contexts (see e.g., Cole et al., 2020; Gibson, 2020; Luo and Kostandini, 2021; Mohan, 2017). The SCM is "arguably the most important innovation in the policy evaluation literature in the last 15 years." (Athey and Imbens, 2017, p. 9). This method provides several advantages over other similar methods, e.g., propensity score matching and difference-in-difference (DID). First, it can control endogenous problems due to selection bias and other factors associated with control group selection and relaxes the parallel trend assumption of the DID method (Li et al., 2020; Olper et al., 2018). Second, it does not calculate weights without using the post-intervention data (Cole et al., 2020).

Following Abadie et al. (2010), we split our sample into two periods, a pre-intervention period, T_0, and the post-intervention period, T_1, where $T = T_0 + T_1$. We assumed there are $K + 1$ countries, among which the first country (i.e., treated unit) was affected by the Artificial Insemination projects over the pre-intervention period $T_0 + 1, \ldots, T$, and the other K countries (so-called "donor pool") is considered as the control samples. The idea of the SCM is to estimate the preintervention characteristics of the treated unit using a weighted average of control units in the donor pool, known as the synthetic control, that approximates the pretreatment outcomes for the treated unit (Abadie et al., 2015; Ben-Michael et al., 2021).

For each country j and time t, let $Y_{j,t}^{I}$ be the production of milk observed for the countries that did not experience Artificial Insemination projects, and $Y_{j,t}^{N}$ be the milk production for the treated unit (i.e., Senegal) after it had adopted the projects. Accordingly, the net effect of the initiative ($\rho_{j,t}$) for the treated unit is defined by the gap between $Y_{j,t}^{N}$ and $Y_{j,t}^{I}$, as follows:

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$$\rho_{j,t} = Y^{I}_{1,t} - Y^{N}_{1,t} \tag{1}$$

It is assumed that the Artificial Insemination projects have no effects on production in the preintervention period, i.e., $Y^N_{j,t} = Y^I_{j,t}$ so for $t < T_0$ and all units. We define $D_{j,t}$ as an indicator that takes the value 1 if country j is exposed to the Artificial Insemination projects at time t, and zero otherwise. Accordingly, the observed outcome for country j at time t is

$$Y_{j,t} = Y^N_{j,t} + \rho_{j,t} D_{j,t} \tag{2}$$

According to Abadie et al. (2010), the potential effect of the intervention for the affected country on our study (Senegal) in period $t > T_0$ is measured by

$$\rho_{j,t} = Y^I_{1,t} - Y^N_{1,t} = Y_{j,t} - Y^N_{1,t} \tag{3}$$

Since $Y^I_{1,t}$ is known, one can estimate the post-intervention trend of milk production by estimating $Y^N_{1,t}$ which is the milk production of Senegal where no intervention occurred. Abadie et al. (2010) apply the following linear factor model to estimate $Y^N_{j,t}$.

$$Y^N_{j,t} = \beta_t + \theta_t X_j + \delta_t Z_j + \varepsilon_{j,t} \tag{4}$$

where β_t denote the time-variant fixed effect, X_j are the observed variables, and Z_j is the unobserved variable affecting milk production, and $\varepsilon_{j,t}$ is the random error term with zero means. According to Abadie (2021), a weighted average of units in the donor pool may approximate the characteristics of the treated unit much better than any untreated unit alone. Given a set of weights for each untreated unit $W = (w_2, \ldots, w_{J+1})'$, a synthetic control estimate of $Y^N_{1,t}$ is

$$\hat{Y}^N_{1,t} = \sum_{j=2}^{J+1} w_j Y_{j,t} \tag{5}$$

where $\hat{Y}^N_{1,t}$ stands for counterfactual domestic production. In Equation (5), the weights are assumed to be nonnegative and sum up to one, i.e., $\sum_{j=2}^{J+1} w_j = 1$. An optimization algorithm is applied to determine the optimal weights (w_j) by minimizing the deviation of the outcome variable path of the synthetic treatment country for the preintervention period (Abadie and Gardeazabal, 2003).

4.2. Data, Measures, and Donor Pool Selection

We use the annual panel data from 1975 to 2018. As mentioned earlier, genetic improvement policies are the major interventions in the dairy sector of Senegal. In this line, we sought to evaluate the effects of the recent Artificial Insemination projects that began in 2008, giving a preintervention period of 33 years to assess the trajectory of domestic production of milk. The study data were taken from the FAO database. To estimate the effects of the policies on domestic production, we use the most recent data on domestic production, powdered milk imports, livestock numbers, the rural and urban population, and the decennial averages of milk production as explanatory variables. A treatment group was constructed using a convex combination of the potential comparison of African countries in the donor pool. The donor countries are most similar to Senegal in terms of preintervention volume of milk production, while they did not experience the same policy intervention. We select the comparative countries in the donor pool using literature and expert opinions. Besides, we choose countries that have data for the whole research period in the dataset to ensure that the weights of the units in the donor pool are not altered over time. Next, we use water footprint data to estimate the policy's impact on water resources. The water requirement for dairy production was assessed by referencing the blue and green water footprints for fresh milk which are estimated at 107 and 1,185 m^3 per ton of milk

Table 1. Country weight that constitutes synthetic Senegal

Country	Weight
Central African Republic	19.1%
Angola	32.4%
Chad	23.2%
DR. Congo	24.3%
Mali	0.10%
Sum	100%

Source: Own calculation using Stata 17.

(Owusu-Sekyere et al., 2016)[12]. Accordingly, producing 251 thousand tons of fresh milk in 2018 required 0.027 billion m^3 of blue and green water, accounting for 1.2% and 13.4% of Senegal's annual water withdrawals, respectively (FAO-AQUASTAT, 2021).

5. Results and Discussion

5.1 The Effects on Domestic Production

Evaluation of our empirical findings determines how milk production evolved in Senegal after 2008 in the absence of Artificial Insemination projects compared to the actual production trend. This was done by constructing an appropriate synthetic control group while holding all other factors constant. Our results in Table 1 imply that synthetic Senegal is best projected by a weighted average of five countries, including Angola (0.32%), the Central African Republic (0.19%), Chad (0.23%), the Democratic Republic of the Congo (0.24%), and Mali (0.01%), which constitute synthetic Senegal. Moreover, as shown in Appendix A, synthetic Senegal closely reproduces the pre-2008 characteristics of milk production in Senegal.

Figure 4 shows the trend in the milk production trajectory of Senegal and its synthetic counterparts from 1975 to 2018. Although synthetic Senegal very closely tracks the trajectory of milk production in the preintervention period, the two lines diverge from each other notably in the post-2008 period. This means that synthetic Senegal provides a sensible approximation for the preintervention period. Our findings indicate that domestic milk production increased at a rapid pace in the post-intervention period, as illustrated in Figure 5. The divergence in the synthetic and treated units shows that the recent Artificial Insemination projects (PSIA and PRADELAIT) had a positive effect on domestic production during the post-2008 period. From 2008 to 2018, the potential effects of Artificial Insemination projects in Senegal account for an average of 59 thousand tons of milk per year. Figure 5 further indicates that production changes as a percentage of annual milk production stood at 37% in 2009 (the year after the implementation of PSIA) and 47% in 2018. From 2008 to 2018, the production of milk in Senegal grew by 66% in total. The difference between counterfactual synthetic growth and actual milk production growth is approximately 40% over the post-intervention period. Most of the growth (40%) can therefore be attributed to the projects. As laid out above, the production objective of PSIA was to obtain additional milk production of up to 400 million liters by 2012 (Seck et al., 2016). Our findings are in line with previous work that Artificial Insemination initiatives have the potential to improve pregnancy rates, which may eventually lead to higher milk production (e.g., Bouyer, 2016; Magnani et al., 2015). However, the results

[12]Blue water is "equal to the volume of fresh surface water and groundwater that is withdrawn and not returned because the water evaporated or was incorporated into a product", while green water is defined as the rainwater that is stored in the soil (Mekonnen and Hoekstra, 2016).

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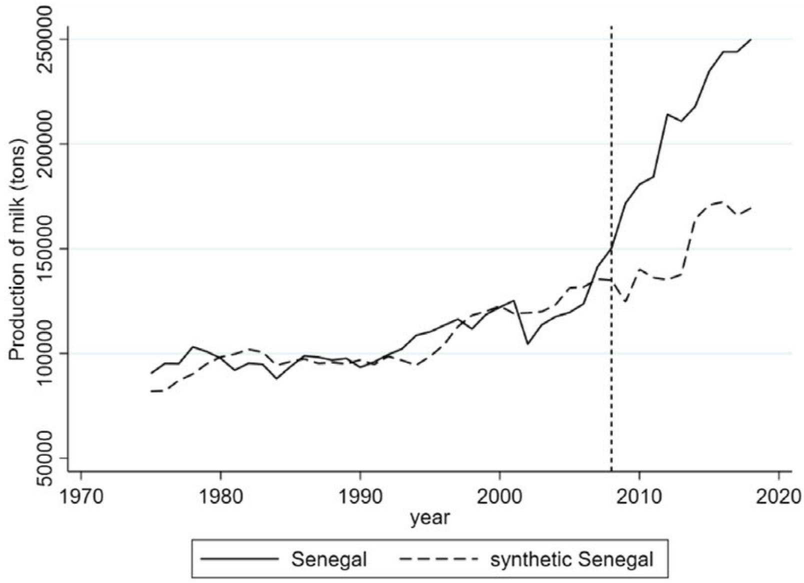

Figure 4. Actual milk production of Senegal vs. synthetic Senegal.
Source: Own calculation using Stata 17.

Figure 5. Gap in milk production in Senegal.
Source: Own calculation using Stata 17.

imply that only 55% of the initial objective were achieved by 2012. McDermott et al. (2010) identify ways to sustain the intensification of smallholder livestock systems in the tropics. This study also indicates that Artificial Insemination could lead to gains of 60% to 300% in milk productivity in cattle, with accompanying changes in feed regimes. Additionally, it is more profitable than natural service even under less than average management conditions since it eliminates the cost of feed and depreciation of keeping natural service bulls (Valergakis et al., 2007; Valergakis, 2000). More importantly, Artificial Insemination also increases long-term herd health by eliminating venereal diseases (Shehu et al., 2010). However, there are different factors

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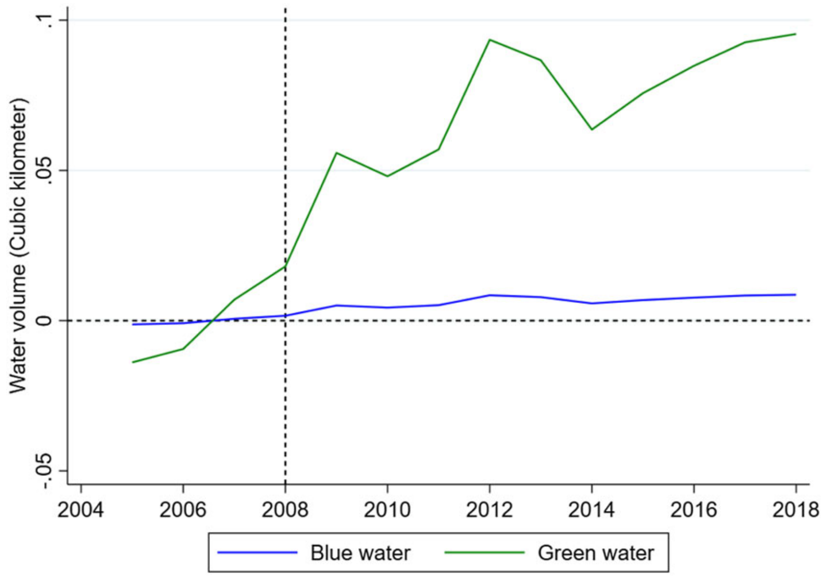

Figure 6. Extra water required for Artificial Insemination projects.
Source: Own calculation using data from Owusu-Sekyere et al. (2016).

and challenges to hinder the real outcomes of Artificial Insemination projects in Senegal. The section that follows discusses the role of water resource scarcity in obtaining the project outcomes.

5.2. The Effects on Water Resources

The water-related issues including water shortages and unequal water distribution over seasons or regions have become a national concern in Senegal (Faye et al., 2019). From January to June, the average precipitation is minor across the country, which may affect the supply of animal feed and, as a result, the cost of production during these months. Besides, the average precipitation in the north is significantly lower than in southern regions. In 2018, withdrawals from water resources in Senegal accounted for 2.22 billion m^3, of which 93% was used for agriculture (FAO-AQUASTAT, 2021).

The dairy sector of Senegal has been facing several challenges including water resource scarcity and harsh environmental conditions (Duteurtre et al., 2021; Marshall et al., 2016; Raile et al., 2019). Due to water resource shortage, herder, especially in the northern region, rely heavily on groundwater, as the average rainfall is low and erratic (Seck et al., 2016). In this sense, the water used for milk production not only involves drinking water for cattle but also influences forage and animal feed availability. Thus, in our analysis, we consider Blue Water used for watering animals as well as Green Water, which corresponds to the sum of soil evaporation and plant transpiration, mainly related to feeding animals (Duteurtre et al., 2021). Using the water footprint of fluid milk estimated by Owusu-Sekyere et al. (2016), we calculate the water required for implementing Artificial Insemination projects in Senegal from 2008 to 2018. Figure 6 indicates the volume of water required to achieve the outcome of the projects. Although our previous findings highlight the positive effects of Artificial Insemination projects on domestic production of milk production, this outcome requires extra pressure on water resources. Based on our estimates for implementing the Artificial Insemination projects from 2008 to 2018, 0.84 cubic kilometers (km^3) of extra water were required in total, consisting of 0.07 and 0.77 km^3 of blue

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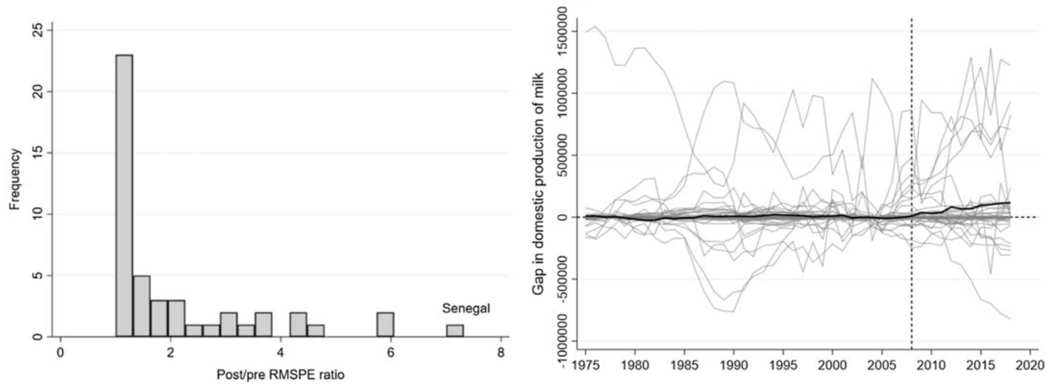

Figure 7. Placebo test results. *Note*: The solid black line in the right graph denotes synthetic Senegal. *Source*: Own calculation using Stata 17.

and green water,[13] respectively. In 2018, the total extra water required for Artificial Insemination projects accounted for 5% of the annual agricultural water withdrawals in Senegal. It is worth noting that apart from the positive effects of Artificial Insemination projects on domestic production, there is still a huge gap between total imports and production in Senegal. To bridge this gap by reducing the dependency on imports, more water resources might be required, which is a serious constraint for domestic production.

To check for the credibility and robustness of our findings, we further carried out a placebo test as suggested by Abadie et al. (2015). We iteratively estimate the baseline model to construct the control placebo estimates for countries that did not experience the same interventions. The placebo is a test of whether a similar pattern for the post-intervention period can be obtained if one had randomly chosen another country as an alternative to Senegal. Thus, we estimate synthetic control for countries that did not experience the same policy interventions in the pre-2008 period. Applying this idea to each country in the donor pool allows us to compare the effects of the policy intervention in Senegal with the distribution of placebo effects for the other countries in the donor pool. Furthermore, the magnitude of the milk production gap between factual and synthetic trends is measured using root mean square prediction errors (RMSPE). Figure 7 presents the ratios between the post and pre-intervention RMSPE for Senegal and all the countries in the donor pool. As shown in Figure 8, Senegal has the largest ratio, which provides evidence of the statistical significance of the results.

5.3. Synergies and Trade-Offs Between Policy Objectives in the Dairy Sector

Based on the findings discussed in the previous section, this section elaborates on the possible interaction and coherence between policy objectives in the dairy sector of Senegal. We first highlight the policy objectives and challenges that Senegal's dairy sector policymakers face. Furthermore, we shed light on the implications of our empirical findings given the interconnection between different policy objectives. A breakdown of Senegal's public expenditures on food and agriculture could reflect the significance of food security and water-related initiatives. The Senegalese Government spent USD 349 million on food security-specific actions in 2020. A major share of this budget (64%) was aimed at making food available to people, mainly through subsidies and irrigation projects (Pernechele et al., 2021). As previously stated, one of the five thematic areas targeted by Senegal's dairy policymakers is access to natural resources such as water

[13]For definition of blue and green water, please check previous sections.

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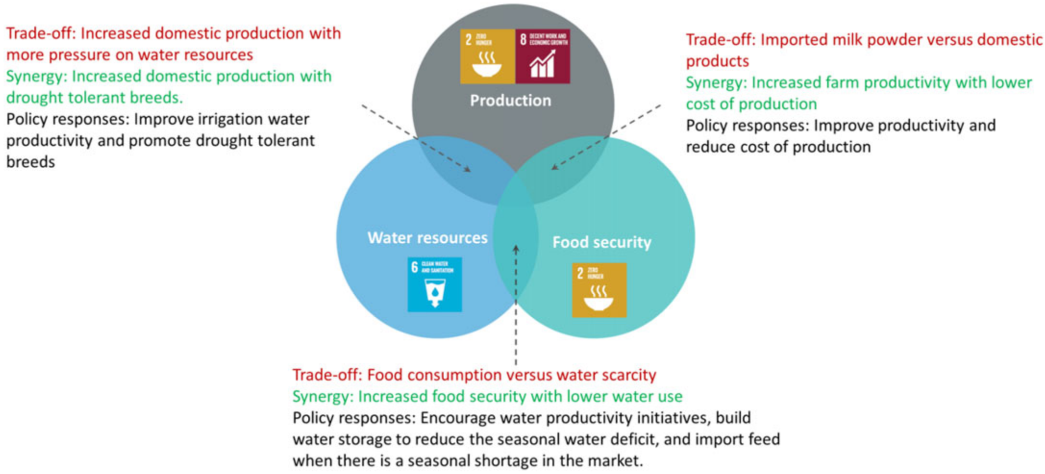

Figure 8. Synergies and trade-offs between policy objectives in the dairy sector.
Source: Own presentation.

and land. Moreover, improving domestic dairy production has long been a priority for Senegalese policymakers (Magnani et al., 2019). Accordingly, we identified three main challenges in the dairy sector of Senegal, domestic production, food security, and water resource scarcity.

Following OECD (2021), we use a simplified framework as illustrated in Figure 8 to explain the interactions between main policy challenges in the Senegalese dairy sector. As the figure suggests, policies in one dimension may have spillover effects on other areas that can be explained in the form of building synergies and trade-offs between the policy challenges. By increasing the low levels of per capita milk consumption, genetic improvement policies improve the productivity and profitability of dairy cattle. This can positively affect food security in Senegal (a synergy). Furthermore, lower production costs make domestic production more competitive compared with imported products and more affordable to domestic consumers (a synergy). Higher domestic production, however, may exacerbate water scarcity (a trade-off), especially during drought seasons. Accordingly, the interactions between different policy objectives need to be considered in formulating policies to prevent unintended externalities (in the case of trade-offs) or to be able to attain all possible benefits (in the case of synergies).

6. Summary and Concluding Remarks

This paper investigates the effects of public interventions on production in Senegal's dairy market. This is accomplished by reviewing literature and milk production trends in order to assess the potential effects of Artificial Insemination projects on domestic milk production via a comparative case study developed by Abadie and Gardeazabal (2003) and Abadie et al (2010). The SCM calculates a weighted average of potential comparative countries that were not affected by Artificial Insemination projects to form a "synthetic" control group with characteristics similar to Senegal prior to intervention. Furthermore, to investigate the short and long-run causal effects, we project the spillover effects of increasing milk production on water resources as an important constraint in the agriculture sector of Senegal and discuss the possible synergies and trade-offs between food security, water resources, and milk production.

This study complements previous descriptive analyzes by providing empirical evidence on the impact of interventions regarding livestock genetic improvements in Senegal. Our findings show that the Artificial Insemination projects caused milk production to increase by 59 thousand tons

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on average from 2008 to 2018 (equal to 651 thousand tons in total). From our estimates, production changes as a percentage of annual milk production stood at 37% in 2009 and 47% in 2018. According to Marshall et al. (2016), an increase in domestic production with higher productivity (e.g., more productive breeds) may benefit food security by increasing milk consumption. Nonetheless, we lack sufficient information to accurately estimate the potential effects on food security. This could be a venue for future research.

While Artificial Insemination projects have increased milk production to some extent, Senegal's market trend shows a significant gap between imports and domestic milk production. This shows that the primary goal of these projects was not achieved. Different barriers hinder the real impacts of Artificial Insemination projects. Water scarcity in Senegal can be considered a negative externality to milk production. Our results highlight the significant effects of dairy sector development on water resources in Senegal. Apart from the direct effect of water scarcity on livestock watering in dairy production, livestock feed production is highly dependent on the constant availability of water throughout the year. For instance, the water required for implementing Artificial Insemination projects in 2018 was estimated at 5% of total agricultural water withdrawals in Senegal, which can be used in other sectors with higher water productivity. The dry season which spans from November to May is a period during which rainfall ceases entirely in Senegal. Access to good quality feed and water is a great challenge and results in low milk yields. Meanwhile, milk production in terms of quantity and quality begins with what animals feed on. Thus, the factors and challenges impeding the actual outcomes of Artificial Insemination should be considered in order to improve the efficiency of genetic improvement policies. Furthermore, Senegalese policymakers should ensure that the negative externalities of production changes do not outweigh the positive effects.

Overall, our analysis suggests that dairy policies should be based on a better understanding of the interdependence and coherence of various policy objectives. This helps policymakers identify the synergies and trade-offs between policy objectives and improves policy efficiencies. It should be noted that better animal health and nutrition are required for the successful implementation of Artificial Insemination projects; otherwise, genetic improvement will have little effect on production. For instance, the more confined dairy systems, particularly those around Dakar, address nutrition, health, and genetics. Therefore, feed and herd health management are critical for the development and continued success of an Artificial Insemination project. As previously stated, it is especially important when the feed market faces a shortage due to the drought. Promoting drought-tolerant breeds may improve the synergy between milk production and water resources. Additionally, feed imports during drought seasons may prevent feed price increases and thereby prevent the increase in production costs when the market faces shortages.

Additionally, the lack of experience of technicians is identified as a significant challenge in implementing Artificial Insemination projects. Therefore, the government should arrange more training programs for technicians to improve their skills and enhance the cattle artificial insemination success rate. Also, dairy farmers should be trained on how to recognize estrous signs in dairy cows to improve reproductive efficiency. Last but not least, the effects of using Artificial Insemination are broader than genetic improvement, and it has a range of benefits for dairy farmers, such as the elimination of venereal diseases, more accurate dry-off dates, reduced incidence of dystocia, and increased safety for farm workers (Vishwanath, 2003). In light of the fact that our approach assesses the genitive improvement policies from an economical perspective, future research on the economic implications of technical requirements in implementing policies may be worthwhile.

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Conflict of Interest. The authors have no conflicts of interest to declare.

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Appendix A

Variable	Treated	Synthetic
The logarithm of powdered milk imports	6.809	6.723
The logarithm of livestock numbers	14.048	13.984
The logarithm of the rural population	8.309	8.736
The logarithm of the urban population	7.701	7.701
Milk production (2005)	119,615	121,369.6
Milk production (1975-85)	95,166.64	93,460.28

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