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COULD GENERIC IMPROVEMENT POLICIES BOOST MILK PRODUCTION IN SENEGAL? A SYNTHETIC CONTROL MECHANISM

Omid Zamani¹, Anoma Gunarathne

Summary

The study elaborates the potential synergies and tradeoffs between the policy objectives in the Senegalese agricultural sector. Here, we focus on genetic improvements. In our empirical analysis, we study the effects of the artificial insemination (AI) projects on dairy production in Senegal over the 2002-2018 period. Thus, we employ the Synthetic Control Method (SCM) for comparative case studies which allows comparison between the trajectories of post-intervention production of milk in Senegal with a combination of similar but untreated countries. We found evidence that the AI projects caused milk production to increase by 59,161 tons on average from 2008 to 2018, which might be positively correlated with food security (i.e. synergies). However, this may put significant pressure on water resources in Senegal. Thus, the negative externality of these projects (i.e. tradeoffs) on water resources should be considered to achieve a more efficient outcome.

Keywords

Livestock improvement, Dairy production, Dairy policy, Senegal.

1 Introduction

In Senegal, agriculture remains the primary means of livelihood, especially for the 8.6 million population living in rural areas (FAOSTAT, 2018). Despite the lower contribution of the agricultural sector to the whole 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 sectors in Senegal, as it plays a vital role in their daily cash income and food and nutrition security (WOLFENSON, 2013). However, dairy production is not able to meet domestic demand, therefore, large amounts of milk, mainly in the form of powdered milk, are annually imported (FAOSTAT, 2019)². 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 shown a renewed interest in developing domestic production (MAGNANI et al. 2019).

The low milk production is primarily caused by the lower milk yield in Senegal which is attributed to the low genetic potential of the indigenous cattle breeds (Marshall et al., 2016; Diouf et al., 2016). Besides, climatic conditions such as water resource scarcity and extreme temperature as well as poor feed, in terms of quality and quantity, are identified as the other factors explaining the gap between the potential and actual yield of dairy products in Senegal (NIEMI et al., 2016; MARSHALL et al., 2016; RAILE et al., 2019). To improve milk yield and thereby increase production, the Government of Senegal has given high priority to livestock development and encouraged private initiatives into dairy development (DIOUF et al., 2016). Among other initiatives, genetic improvement of local cattle breeds through Artificial Insemination (AI) has been considered the preferred strategy for improving milk yield from indigenous breeds (SECK et al., 2016).

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² In 2018, 251 thousand tons (milk equivalent) of dairy products were produced in Senegal, while 595 thousand tons were imported.

Since the 1990s, several genetic improvement initiatives have been implemented in Senegal. However, due to a lack of data, research studies evaluating dairy interventions are limited in Senegal. To the best of our knowledge, no previous work has empirically analyzed the impacts of the main dairy policies on milk production in Senegal. In this study, we contribute to the literature by empirically investigating the potential effects of the major policy interventions in the dairy sector including the artificial insemination initiatives on domestic milk production in Senegal. The study objectives are indicated threefold. First, we identified the most influential policies in the dairy sector of Senegal from 1990 to 2019 by reviewing the trend of domestic milk production. Second, we assessed the effect of identified policies using the synthetic control approach. Finally, we identified the potential barriers to dairy production including water resource scarcity and explored ways to optimize policy intervention options.

The remaining sections of this paper are structured as follows: Section 2 presents the general overview of the dairy sector. Section 3 explains the dairy policies and programs. Section 4 describes the methods of analysis. Finally, section 4 summarizes the key findings.

2 Overview of the dairy sector in Senegal

The livestock sector has been playing a significant role by improving household income and food security for subsistence farmers and pastoralists in Senegal. Senegal's livestock sector mainly comprises cattle, goats and sheep, and poultry. Most of the small rural households are engaged in traditional poultry raising. Livestock accounts for only about 3.6% of national GDP, but it is an integral part of many other agricultural enterprises providing draught power, organic fertilizer, and transport (ANSD Senegal, 2020). In Senegal, milk is a product of great socio-economic and nutritional importance where the national supply is not able to meet the growing demand for milk and dairy products. Currently, Senegal is only 66% self-sufficient with its milk production, and this resulted in the importation of about 100,000 metric tons of powdered milk, spending more than US\$ 400 million per year to fulfill domestic demand (ZAMANI et al., 2021).

Figure 1. Development of the Dairy Sector in Senegal from 1996 to 2018 (in 1000 tons, milk equivalent)



Note: The domestic consumption is estimated based on imports + production - exports. Storage was not considered. The artificial insemination policies are presented in black and the other livestock policies are in red. The policies are discussed in the following section in detail. Source: Exports and imports are based on UN COMTRADE (2018). The production data is retrieved from FAO (2018).

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. 2017). As a result, ZAMANI et al. (2021) investigated that between 2000 and 2018, the self-sufficiency rate of the Senegalese dairy sector steadily declined from 41% to 20% (figure 1). This indicates that the dependency on imported milk and milk products will continue to increase in the future.

The cattle population in Senegal amounts to 3.7 million heads, and it represents 1% cattle population in Africa (FAO, 2020). This comprises indigenous and exotic cattle breeds and their cross-breeds. Cattle rearing is classified under three major dairy production systems: pastoral, agro-pastoral, and, most recently, the intensive peri-urban system (figure 2).

The pastoral system: This is an extensive farming system present in two areas in the north and

Figure 2. Location of Dairy Production Systems in Senegal



Source: Own presentation based on DIEYE, 2006

the north-central regions of the country (Ferlo and the Senegal River areas). The Ferlo silvopastoral zone covers a third of the country's landmass and concentrates two-thirds of the total domestic ruminants in Senegal with 15% of the cattle population. This system contributes about 38% of the national milk production (DIOA, 2003) which is mainly exploited from the Gobra zebu cattle breed. Notwithstanding the contribution of this system, there are constraints to production such as irregular water supply which worsens in the dry season, and inadequate health coverage for farm animals. Despite these constraints, this is the only zone that produces a surplus of milk in the rainy season, thus justifying the installation of a milk collection network by Nestlé Senegal between 1992 to 2003.

The agro-pastoral system: These production systems are 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 liters per cow respectively. Artificial insemination first appeared in the groundnut zone in 1994 with the PAPEL project (Projet d'appui à l'élevage), 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 liters/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 AI or natural service depending on the farmer's production goal which could either be dairy or beef products. This decision on the production goal is particularly dependent on the availability of food (forage) in the dry season, difficulties in marketing dairy products, the low success rate of AI, and its relatively high cost.

The intensive peri-urban system: This system is usually practiced mainly in the Niayes area of Dakar-Thiès. It represents less than 1% of the cattle herd and is primarily based on the use of exotic cows (Montbéliarde, Jersiaise, Holstein, and Gir) in permanent stabling for milk production. Milk production is of the highest interest in this production system and because of that AI is widely applied to increase the production of milk. The average daily milk yield per cow is considerably high compared to the other two systems with the production of 30.0 liters in the rainy season (Jan-Mar) and 15.0 liters in the dry season (April-Dec).

The dairy sector has been facing several challenges including water resource scarcity and harsh environmental conditions (MARSHALL, 2016; RAILE et al., 2019). 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). Like other countries in Africa, the agriculture sector uses the major share of freshwater for production. In 2018, withdrawals from water resources in Senegal accounted for 2.22 billion m³, out of which 93% was used for the agriculture sector (FAO-AQUASTAT, 2018). Apart from the direct effect of water scarcity for livestock watering in dairy production, the production of livestock feed is highly dependent on the constant availability of water throughout the year.

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 improving farmers' livelihood (DEMONT and RIZZOTTO, 2012). After an expensive period of state intervention between the 1960s and 1980s, Senegal adopted the structural adjustment programs in agriculture (PASA) 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 (WEISSMAN, 1990; Resnick and BIRNER, 2010).

In the dairy sector, reduction of import dependency through increasing domestic production is a central objective for public interventions that are jointly implemented by the private sector (to carry out livestock vaccination), NGOs, and public projects (DIEYE et al., 2005). The policies in the dairy sector 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 macroeconomics policies (DIEYE et al., 2005; SECK et al., 2016).

Adopted in 2004, the Agriculture, Forestry, and Livestock Act (LOASP) represents an important institutional framework for reviving the agricultural sector of Senegal (WTO, 2017). Aiming 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), and the Grand Agricultural Offensive for Food and Abundance (GOANA). 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 the interventions in the livestock sector (SECK et al., 2016). 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 (WTO, 2017; SECK et al., 2016; WORLD BANK, 2020). 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 to 64 million Euro) (DUTEURTRE, 2009). However, the 2007-2008 food price spike highlighted the high vulnerability of Senegal's food security to the international food price variations (SECK et al., 2016). As result, on one hand, several contingency policies were taken to control milk price including tax exemptions for powdered milk imports. On the other hand, to reduce Senegal's food dependency, the government implemented GOANA in 2008, which comprise technical elements like animal feed, cross-breeding, and artificial insemination, as well as trade-related policies such as tax exemptions for production inputs and the processing of local milk (MASANGI et al., 2021; DEMONT and RIZZOTTO, 2012). Nevertheless, due to a lack of finance, only artificial insemination effectively became operational under the GOANA project which finances breeding and genetic improvement (MASANGI et al., 2021). 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.

3.1 Artificial Insemination and Genetic Improvement Programs

In Senegal, as in most tropical countries, genetic improvement has always been the cornerstone of dairy policies. As indicated above, artificial insemination has been widely supported by successive national programs. Subsidized by the public sector, all dairy genetic improvement programs in Senegal³ have been implemented at no cost to cattle keepers (MARSHALL et al., 2016). The main stakeholders of the genetic improvement program include the state, livestock professionals, public services, and private companies, including veterinarians, livestock engineers, and livestock technicians, and the dairy farmers are the main beneficiaries (DIOUF et al., 2016).

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 (AfDB). Under this project, around 5000 cows located in these production zones were inseminated during 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. The decrease in the pregnancy rate in 1997 was most likely due to the shortage of forage in that year (SECK et al., 2016). The PAPEL project was followed by the Agricultural Development Project of Matam (PRODAM) in northern Senegal. Under this project also, 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 (BOUYER, 2016).

Again, as part of the national milk production development policy, three breeding campaigns were conducted under the national artificial insemination program (PNIA) in 1999, 2001, and 2004. This was done predominantly by private companies using protocols defined based on the specifications of agro-ecological zones. As a result, between 1999 to 2001, the overall insemination success rate enhanced from 31% to 42% (MAE, 2002a; MAE, 2002b; MAE, 2002c; MASANGI et al., 2021; GUEYE, 2003). Although there was an increment in the success rate, feeding challenges, inadequate experience of AI technicians, and geographic dispersion of activities were identified as some of the significant barriers that negatively impacted AI programs. This impact 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.

³ except two campaigns.

Later on, the GOANA program was implemented in 2008 to boost livestock production through the implementation of different genetic improvement initiatives (CABRAL, 2016). The GOANA livestock project and the Special Artificial Insemination Program (PSIA) ran simultaneously as autonomous programs of genetic improvement from 2008 to 2014. The production objective of PSIA was to inseminate 500,000 cows by 2012 with the expectation of obtaining 100,000 crossbreed and additional milk production of up to 400 million liters. Under this program, 116,024 cows were inseminated with a success rate of 42.5% from 2008 to 2014 (MEPA, 2012 and 2014). It is as a result of this foresight that the Government of Senegal presented AI as the best technical option to rapidly increase national milk production and reduce imports. Due to some good progress by the government, the insemination programs were made to showcase the presidential commitment to modernity and which testifies to a growing "technicist" attitude in dairy development (MAGNANI, 2016: 143-158). The goal of the PSIA (2010-2011) insemination program was to inseminate 20,000 cows, out of which 19,209 were inseminated, representing 96% of the targeted population of cattle (SECK et al., 2016). However, the evaluation of PSIA highlights a reduction in pregnancy rate from 47.4% to 44.2% over the implementation period (SECK et al., 2016). Additionally, critics have expressed concern about the lack of effective monitoring of the project outcomes which are necessary for making the profitability evaluation of the project challenges.

In line with its vision and despite the challenges with PSIA, the government decided to continue the genetic improvement plan through the Dairy Industry Development Support Project (PRADELAIT - Projet d'Appui au Développement et à la Modernisation de la Filière Lait). This project was carried out within the framework of the 2014-2018 Emerging Senegalese Plan (PSE) with a budget of 30 million euros (DIOUF et al., 2016). The PRADELAIT project shared similar aims with PSIA as it also seeks to improve milk production through the intensification and modernization of production systems. The goal of the project was to contribute to the creation of jobs, income generation and mitigate extreme poverty as well as improve food security, especially in rural areas. Finally, 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. This advocacy was aimed at promoting the domestic consumption of milk in producer countries such as Burkina Faso, Mali, Mauritania, Niger, Ghana, and Senegal (GRET, 2019). Figure 3 shows the timelines of AI and livestock improvement projects implemented in Senegal.





4 Data and 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 proposed the synthetic control method (SCM) (OLPER et al., 2018). Over the last decade, SCM has been widely used for estimating the effects of interventions in different contexts (see e.g. MOHAN, 2017; COLE et al., 2020; ABADIE, 2021). In this paper, we used the Synthetic Control Method (SCM) to estimate the effects of AI projects on dairy production in Senegal. Additionally, we projected the potential effects on water resources as one of the key constraints of the Senegalese dairy production. The SCM provides several advantages over other similar methods, e.g. propensity score matching (PSM) 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 (OLPER et al., 2018; LI et al., 2020). Secondly, SCM 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 AI projects over the pre-intervention period $T_0 + 1, ..., T$, and the other K countries (so-called "donor pool") is considered as the control samples. The idea of SCM is to estimate the pre-intervention characteristics of the treated unit using a weighted average of control units in the donor pool, known as the synthetic control, that approximate the pre-treatment outcomes for the treated unit (ABADIE et al., 2015; BEN-MICHALE 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 the AI projects, and $Y_{j,t}^{N}$ be the milk production for the treated unit (i.e. Senegal) after it had adopted the AI projects. Accordingly, the net effect of the AI projects ($\rho_{j,t}$) for the treated unit is defined by the gap between $Y_{i,t}^{N}$ and $Y_{i,t}^{I}$, as follows,

$$Eq(1) \quad \rho_{j,t} = Y_{j,t}^N - Y_{j,t}^I$$

Following ABADIE et al. (2015), it is assumed that the AI projects have no effects on production in the pre-intervention period, i.e. $Y_{j,t}^N = Y_{j,t}^I$ so for $t < T_0$ and all units. We define $D_{j,t}$ as an indicator that takes the value 1 if the country j is exposed to the AI projects at time t, and zero otherwise. Accordingly, the observed outcome for country j at time t is,

$$Eq(2) \quad Y_{j,t} = Y_{j,t}^N + \rho_{j,t} D_{j,t}$$

Following 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 ABADIE et al. (2010),

Eq(3)
$$\rho_{j,t} = Y_{1,t}^I - Y_{1,t}^N = Y_{j,t} - Y_{1,t}^N$$

Since $Y_{1,t}^I$ is known, one can estimate the post-intervention trend of milk production by estimating $Y_{1,t}^N$ which is the milk production of Senegal where no intervention occurred. ABADIE et al. (2010) applies the following linear factor model to estimate $Y_{i,t}^N$.

Eq(4)
$$Y_{j,t}^N = \beta_t + \theta_t X_j + \delta_t Z_j + \varepsilon_{j,t}$$

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. $\varepsilon_{j,t}$ 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 $W = (w_2, ..., w_{J+1})'$, a synthetic control estimates of $Y_{1,t}^N$ is:

Eq(5)
$$\hat{Y}_{1,t}^N = \sum_{j=2}^{J+1} w_j Y_{j,t}$$

Where $\hat{Y}_{1,t}^N$ stands for the counterfactual domestic production. In Equation (5), the weights are assumed to be nonnegative and sum up to one, i.e. $\sum_{j=2}^{J+1} w_j = 1$. Following ABADIE and GARDEAZABAL (2003), 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 pre-intervention period.

4.1 Data, measures, and donor Pool selection

We use 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 aimed to assess the effects of the recent artificial insemination projects that started in 2008, giving a preintervention period of 33 years to assess the trajectory of the domestic production of milk. The study data was taken from the FAO database. To estimate the effects of the policies on domestic production, we used 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 by a convex combination of the potential comparison of African countries in the donor pool that is most closely similar to Senegal in terms of pre-intervention volume of milk production. We selected the comparative countries in the donor pool using literature and expert opinions. Moreover, the water requirement for dairy production was assessed by referencing the blue and green water footprints for fresh milk which is estimated at 107 and 1185 m3 per ton of milk (OWUSU-SEKYERE et al., 2016). Accordingly, it was estimated that producing 251 thousand tons of fresh milk in 2018 required 0.027 billion m3 of blue and green water, accounting for 1.2% and 13.4% of annual total water withdrawals in Senegal respectively (FAO-AQUASTAT, 2018).

5 Results

Evaluation of the synthetic control method (SCM) determines how milk production evolved in Senegal after 2008 in the absence of AI policies compared to the actual production trend. This was done by constructing an appropriate synthetic control group while holding all other factors constant. Our findings in Table 1 imply that synthetic Senegal is best projected by a weighted average of 5 countries, including Angola (0.32%), 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 I, synthetic Senegal closely reproduces the variables for the pre-2008 period of milk production in Senegal.

Table 1.	Country weight that	constitutes synth	etic Senegal
		•	0

	-
Country	Weight
Central African Republic	0.191%
Angola	0.324%
Chad	0.232%
DR. Congo	0.243%
Mali	0.010%
Sum	100%

Source: Own calculation using STATA 17.

Figure 5 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 pre-intervention 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 pre-intervention period. Our findings suggest that the domestic production of milk in the postintervention period increases at a growing pace as also indicated in Figure 5. The divergence in the synthetic and treated unit shows that the recent AI projects (PSIA and PRADELAIT) had a positive effect on domestic production during the post-2008 period. As mentioned earlier, the gap between the treated unit and synthetic Senegal demonstrates the potential effects of the AI projects in Senegal, which accounts for 59 thousand tons of milk annually on average. Figure 4 further shows that production changes as a percent of annual milk production stand at 27% in 2009 (the year after the implementation of PSIA) and 32% in 2018. From 2008 to 2018, the production of milk in Senegal grew by 66% in total. Compared with counter-factual synthetic Senegal, our results illustrate that milk production changed by 40% over the post-intervention period. Given the fact that the main dairy policy over the post-2008 period are AI and genetic improvements projects (as discussed in the previous section), the observed changes might be majorly driven by these 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 AI 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 imply that only 55% of the initial objective were achieved by 2012.



Source: Own calculation using STATA 17.

5.1 The effects on water resources depletion

The dairy sector of Senegal has been facing several challenges including water resource scarcity and harsh environmental conditions (MARSHALL, 2016; RAILE et al., 2019; DUTEURTRE et al., 2021). Water scarcity not only has a direct effect on livestock watering but also influences forage and animal feed availability. Due to water resource shortage, herders, 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 the water used for upstream production of feed and the downstream processing of products. 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 AI projects in Senegal from 2008 to 2018. Figure 6 indicates the volume of water required to achieve the outcome of the AI projects. Based on our estimates for implementing the AI projects from 2008 to 2018, 0.84 cubic kilometers (km³) of extra water is required in total, consisting of 0.07 and 0.77 km³ of blue and green water⁴. In 2018, the total extra water required for AI projects accounts for 5% of annual agricultural water withdrawals in Senegal. It is worth noting that, apart from the positive effects of AI 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.



Figure 6. Extra water required for AI projects

Source: Own calculation using data from Owusu-Sekyere et al (2016).

5.2 Robustness Check

To check for the credibility of our findings, we further carried out a placebo study as suggested by ABADIE, DIAMOND, and HAINMUELLER (2015). We iteratively estimated the baseline model to construct the control placebo estimates for countries that did not experience the same interventions such as Ghana. The placebo test is a test of whether a similar pattern for the postintervention period can be obtained if one had randomly chosen another country as an alternative to Senegal. Thus, we estimated 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. To measure the magnitude of the gap in milk production between factual and synthetic trends, we used root mean square prediction errors (RMSPE). Figure 7 presents the ratios between the postintervention root mean square prediction errors (RMSPE) and the pre-intervention RMSPE for Senegal and all the countries in the donor pool. As shown in figure 8, Senegal has the largest ratio of RMSPE, which provides evidence of the statistical significance of the results.

⁴ For definition of blue and green water, please check previous sections.

Figure 7. Placebo test results



Note: The solid black line denotes synthetic Senegal. Source: Own calculation using STATA 17.

5.3. Synergies and tradeoffs between policy objectives in the dairy sector

Using our 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 faced by policymakers in the dairy sector of Senegal. Further, we shed light on the implications of our empirical findings given the interconnection between different policy objectives. A breakdown of public expenditures for food and agriculture in Senegal may reflect the importance 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 mentioned earlier, access to natural resources including water and land is one of the five thematic areas targeted by dairy policymakers in Senegal. Besides that, improving domestic dairy production has been always a prominent goal 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.

The spillover effects between policy objectives underscore the need for increased economic research on the agriculture–poverty–water nexus (BALASUBRAMANYA and STIFEL, 2020). 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 cross-sectoral impacts and spillover effects on other areas that can be explained in the form of building synergies and tradeoffs between the policy challenges. By increasing the low levels of per capita milk consumption, genetic improvement projects may increase the productivity and profitability of dairy cattle which can positively affect food security in Senegal (a synergy). However, higher domestic production may aggravate water scarcity (a tradeoff), especially during drought seasons. The extra water required for implementing the AI projects might be needed in non-dairy sectors that may promote higher water productivity. 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).

Figure 8. Synergies and tradeoffs between policy objectives in the dairy sector



Source: Own presentation.

6 Conclusion

This paper investigated the production effects of public interventions into the dairy market of Senegal. This was done by reviewing literature and trend in milk production to assess the potential effects of AI projects on domestic milk production using the synthetic control method (SCM) for a comparative case study developed by ABADIE and GARDEAZABAL (2003) and ABADIE et al. (2010). More specifically, The SCM uses a combination of African countries, which were not affected by AI projects, to constitute a "synthetic" control group with similar characteristics to Senegal in the pre-intervention period. 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.

Our findings show that the AI projects caused milk production to increase by 69 thousand tons on average from 2008 to 2018 (equal to 759 thousand tons in total). Our estimate also indicates that production changes as a percent of annual milk production were 21% in 2009, 41% in 2015, and 47% in 2018. This in turn induces an increase in water usage for milk production. For instance, the water required for implementing AI projects in 2018 is about 6% of total agricultural water withdrawals in Senegal, which can be used in other sectors with higher water productivity. Thus, the negative externalities of production change may cancel out the positive effects eventually. In line with MARSHALL et al. (2016), an increase in domestic production with higher productivity (e.g. more productive breeds) may positively affect food security, as it may increase milk consumption. Nevertheless, we have no information to estimate the potential effects on food security precisely. Thus, this might be a venue for future studies.

While the AI projects aimed to reduce dependency on imports significantly, yet, the actual trend of the market shows a substantial gap between import and domestic production of milk in Senegal. This is partly due to that the initial goals of these projects have not been achieved. Different barriers hinder the real effects of AI projects. Although artificial insemination services were used to be provided free of charge in the past, the farmers should pay for them now which is cost-prohibitive (CRAIGHEAD et al. 2021). Thus, financial support (subsidies) may improve the final results of AI projects. Additionally, water shortage in hot seasons may prevent farmers to increase production throughout the year. This may cause the feed costs to change seasonally with a peak in summer. In this regard, comprehensive AI projects should be supported by

sufficient water availability and livestock feed throughout the year for optimal milk production and feed conversion efficiency. Last but not least, a more realistic dairy policy should be based on a better understanding of spillover effects and coherency between different policy objectives.

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Appendix I

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 (1975-85)	111079.5	121369.6
Milk production (2005)	95166.64	93460.28

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