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Artificial Insemination, Livestock Productivity and Economic Growth in Senegal

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Abstract

This paper assesses the effects of an artificial insemination program implemented in Senegal's cow sector from 2008 to 2011. The program aimed to boost cow production in order to increase the sector's supply of raw milk, processed milk, processed meat, and leather. We first build a dynamic recursive general equilibrium model in which the total factor productivity (TFP) is endogenized and expressed as a function of i) R&D and externalities for the cross-bred cows and ii) only externalities for traditional cows. We then simulate the effects of the artificial insemination program on sectors and factors remuneration, and hence GDP and welfare. The results show that production of cross-bred and local cows significantly increases under the program, as does production of processed meat, raw milk, processed milk, and leather. However, the increase in TFP seems to have a depressive effect on returns to factors, as less intensive factors used by cow sector are needed to produce the same output. Therefore, income for all households tends to decrease. However, consumption prices also decrease for all households, and the price effects seem to overcome the income effects. Households from sylvo pastoral rural areas, from urban cities (Dakar and other cities), and from the groundnut belt see their welfare increase from this program, while households in Southern Senegal, Eastern Senegal, and the Senegal River and Niayes area see decreased welfare.

Résumé

L'objectif de cette recherche est d'évaluer les effets du programme d'insémination artificielle, mis en œuvre au Sénégal de 2008 à 2011, sur la croissance et le bien-être. Le programme visait à augmenter l'approvisionnement en lait cru, en lait transformé, en viande transformée, et en cuir du secteur de l'élevage. Nous construisons d'abord un modèle dynamique récursif d'équilibre général dans lequel la productivité totale des facteurs (PTF) est endogènéisée et exprimée en fonction i) de la recherche-développement et des externalités dans le secteur des bovins métissés et ii) seulement des externalités dans celui des bovins traditionnels. Nous simulons ensuite les effets du programme d'insémination artificielle sur les secteurs, en particulier celui des bovins, les facteurs de production, le PIB et le bien-être. Les résultats montrent que la production de bovins métissés et locales augmente de manière significative, de même que la production de viande transformée, le lait cru, de lait transformé, et de cuir. Toutefois, l'augmentation de la PGF semble avoir un effet dépressif sur le rendement des facteurs puisque moins de facteurs sont nécessaires pour produire le même niveau d'output. Par conséquent, le revenu de tous les ménages diminue. Les prix à la consommation baissent également pour tous les ménages. Toutefois, l'effet prix semble dominer l'effet revenu. Les ménages des zones rurales sylvo pastorales, de centres urbains (Dakar et d'autres villes), et du bassin arachidier voient leur bien-être augmenter suite à la mise en oeuvre de ce programme tandis que les ménages du Sénégal, du Sénégal oriental, et du fleuve Sénégal et des Niayes voir leur bien-être diminuer.

1. Introduction

Africa south of the Sahara has vast potential to increase the productivity of its livestock sectors. The production of meat per animal in the region is two times less than the average obtained in other developing countries and five times less than the average obtained in developed countries (depending on the species produced). In addition, the production of milk from local breeds is up to 10 times lower than that achieved by European breeds (Boly and Leroy, 1999). Increasing productivity in the livestock sector could play a key role in achieving the ECOWAP goals of reaching a 6 percent average growth rate in the agricultural sector and halving poverty in the region.

In Senegal, the livestock sector makes the largest contribution of any agricultural sector to agricultural value added and incomes. Under ECOWAP predictions, sustained growth in this sector through 2015 would generate an additional US$ 32.2 million (in 2005 dollars). This would induce the highest reduction in the poverty headcount coming from agricultural growth, compared to crops and fishery (République du Sénégal, 2009).

The Senegalese livestock sector contained an estimated 15 354 685 animals in 2011, compared to 14 971 039 animals in 2010. This number is can be broken down into sheep (37.4 percent), goats (31.9 percent), cattle (21.9 percent), pigs (2.38 percent), horses (3.44 percent), donkeys (2.94 percent), and camels (0.03 percent). For poultry, there was 43.6 million head in 2011, compared to 39.3 million head in 2010; this represents means an increase of 10 percent (ITS, 2011). The number of units of eggs produced was 605.5 million in 2011; this increased by 5.4 percent from 2010, when the number was 572.9 million (ITS, 2011). Meat production was estimated at 193,311 tons in 2011 and 176,844 tons in 2010 which means an increase by 9.3 percent. Estimated milk production in 2011 was 231,597 liters in 2011 and 227,904 liters in 2010, an increase of 1.6 percent. Milk products are mainly composed of bovine milk (62 percent), goat milk (23 percent), and sheep's milk (15 percent). The "raw skin" sector (i.e., leather) was estimated at 5 190 tons in 2010 and 5 374 tons in 2011, increasing by 3.5 percent. Finally, the "livestock & hunting" sector contributed about 4.3 percent to the country's GDP in 2011. The GOANA program aims to boost livestock production through the implementation of the National Program for the Development of Local Dairy Die. The first step in this program was an artificial cow insemination program, with the objective of creating a population of 500 000 cross-bred cows by 2012. The program is expected to produce 400 million liters of milk, 43, 500 tons of meat, and 120, 000 pieces of leather. This would greatly reduce milk imports, which have an important weight on the country's trade balance. In addition, it could enhance food security with regards to dairy products. The cumulative insemination from 2008 to 2010 totaled 107, 000 cattle, which equals one-fifth of the original target of 500, 000 cattle. The budget devoted to this program is estimated at CFAF 7.33 million. This limited funding, which is only about 18 percent of the budget necessary, formed a major

constraint to the program's success (République du Sénégal. 2013). Increased funding to artificial insemination programs, as is planned under the National Program of Agricultural Investment (NPAI), to devote more resources to the program, which could significantly increase the performance of the livestock sector in the coming years; this would have important effects on TFP value added and factor demand, as well as on overall GDP growth and household well-being.

Studies on livestock systems can be ranged into three groups depending on technical projects (Tichit et al, 2004). In the first group, the main objective is to perpetuate the breeding herd in the long term. In the second group, the aim is to produce a regular output, even if the numerical and weighted productivity is moderate. For the third group, the aim is a high level of production, with distribution of birth across one or more annual periods. Traditional farming is often characterized by the coexistence of two systems: the transhumant system, which is characterized by high mobility and a weak link with agriculture, and the sedentary system, which can be mixed and combined with different food crops or annuity (Douhoux and Hounsou, 1993; Chentouf et al, 2004).

The literature on livestock activity remains divided regarding the impact of a number of variables on productivity. These variables include age at first calving and calving intervals (Sow et al. 1988; Dehoux and Hounsou, 1993), lactation (Dehoux and Hounsou, 1993), the rate of weaning (Dekhili and Dekhili, 2003), and the fertility rate (Senussi, 2004).

Traditionally, animal reproduction biotechnologies include four steps: artificial insemination, embryo transfer, in vitro fertilization, and transgenesis (Thibier and Guerin, 1993). However, only two genetic improvement techniques are used in Senegal: artificial insemination (AI) and embryo transfer (Beye et al, 2013). Embryo transfer involves removing embryos from donor females and transplanting them into the uterus of recipient females, where they can develop to term (Massip and Dessy, 2005). Artificial insemination consists of depositing the seed harvested first in the genital tract of a female in estrus (Fall, 1995).

AI is the biotechnology breeding technique most widely used worldwide and is one of the most effective tools for disseminating genetic material (Lofti et al, 1996). It enables large-scale screening and can accelerate the pace of milk production. In 1999, the NAIP instituted an AI program spanning the country (Beye et al, 2013). The objective of this program was to increase national milk production through the genetic improvement of local breeds. Another AI program, Senegal's largest, was launched in 2008 to cope with the threat of a national food crisis. However, AI's success rate is still low in Senegal, having never reached 50 percent (in Burkina Faso, on the other hand, the AI success rate is 70 percent) (Ouedraogo, 2012). Senegal's low AI success rate can be attributed to several factors, including the high cost and low availability of nitrogen, mix livestock with a high risk of protrudes of bulls before the insemination process,

nutritional deficiencies that may cause embryonic mortality after insemination, the wrong track heats and starts or late warning (Faye, 2012).

Several models have attempted to endogeneously integrate innovation in economic analysis. For Arrow (1962), knowledge on the TFP is the accidental product of experience in the production of new capital goods. He qualifies this phenomenon as a process of "learning by doing". For Frankel (1962), the accumulation of capital leads to an increase of knowledge. Romer (1986) considers that the producers do not internalize the externalities of knowledge growth. In this context, knowledge is treated as an investment good which is combined with other factors produce a final product.

In another model, Romer (1990) takes into account the specificity of technological knowledge as an economic good. Technology is a non-rival good: the use of knowledge by an agent does not preclude the simultaneous use by another. It is also a well partially exclusive good: it is possible to prohibit the use of knowledge by an agent to produce a good. It is however difficult when this knowledge is used to produce another knowledge. The ownership of a discovery cannot be partial.

For Romer (1990) technical progress and innovation is at the heart of economic growth. It incites to capital accumulation and the combination of factors explains much of productivity gains. The author assumes that technical progress comes from voluntary decisions by individuals who meet the incentives issued by the market. The model therefore includes a rather endogenous technical progress. An additional assumption considered that modalities to implement technological innovations differ from the other technological assets. There was a sunk fixed cost for the first innovation, used as an input, which provides a monopoly rent to the innovative company. Romer found that the increase in innovation depends on both the staff working in research and the number of existing innovations. The total labor supply is a sum of the labor given to the production of good and the one allocated to research. This expresses the existence of dynamic externalities related to research.

This paper aims to assess the effects of artificial insemination on livestock productivity, overall GDP growth, and household well-being in Senegal. For that purpose, I establish an analytical framework that takes into account those feedback effects. A dynamic CGE model is then be used to assess the effect of increased productivity on TFP sectoral reallocation of resources and growth.

2. Background

The livestock sub-sectors and their related outputs (processed meat, raw milk, processed milk, leather, and cows) play a relatively significant role in Senegal’s overall agricultural GDP, and livestock products represent a fairly significant share of household budgets. Moreover, processed products derived from livestock are essentially non-tradable goods, whereas processed livestock products have a high rate of

import penetration, as well as high export rates. Several lessons can be drawn from an analysis of the livestock industry and its related sectors from the 2005 SAM.

2.1 Macroeconomic structure

Crops account for 9.9 percent of Senegal's GDP, and livestock contributes about a quarter of this amount. The livestock sector is also linked to several processing sectors like meat, milk, and leather. In total, the livestock sector and its related sectors account for about 4.7 percent of national GDP.

Table 1: Relative weight of value added in production and share of sectors in total value added (in %)

Sectors	Value added of sector j/Production of sector j	Value added of sector j /Total Value added
Crops	84.5%	9.9%
Fishery	56.8%	1.8%
Cow	49.8%	0.1%
Ovine	89.7%	0.9%
Goat	86.8%	0.5%
Cameline-porcine	86.8%	0.3%
Equine	85.3%	0.1%
Traditional poultry	85.3%	0.0%
Industrial poultry	83.3%	0.4%
Other type of livestock	60.7%	0.3%
Processed meat	67.7%	0.3%
Processed fish	58.3%	1.5%
Leather	41.3%	1.7%
Processed milk	56.1%	0.2%
Other industry	4.8%	0.1%
Tradable services	18.7%	17.4%
Non tradable services	59.6%	46.8%
Total	77.3%	17.8%

Sources: SAM.

2.2 Structure of expenditure and household income

Tables 2 and 3 give us the distribution of household income sources, as well as the allocation of households' income. Given the weakness of human capital in rural areas, the share of skilled labor is relatively low compared with unskilled labor. Thus, urban households receive more wages from skilled labor (Table 2). Sixty-eight percent of the returns from non-agricultural capital goes to urban households, while returns to agricultural capital goes to rural households depending to their endowments. The returns to land factors are fully received by rural households.

Table 2: Structure of factor income for agents

	Qualified labour	**Non qualified labour**	**Crop capital**	**Cow capital**	**Livestock other capital**	**Non agricultural capital**	**Public capital**	**Land**
Firms	0.0%	0.0%	0.0%	0.0%	0.0%	18.1%	100.0%	0.0%
Dakar	65.7%	35.8%	0.0%	0.0%	0.0%	43.1%	0.0%	0.0%
Other cities	13.7%	47.8%	0.0%	0.0%	0.0%	24.8%	0.0%	0.0%
Groundnut belt	1.7%	5.5%	40.2%	5.1%	20.8%	6.2%	0.0%	55.5%
Niayes area	0.5%	1.4%	2.9%	0.4%	12.6%	1.0%	0.0%	3.5%
Southern Senegal	1.8%	2.7%	28.1%	7.4%	18.9%	2.6%	0.0%	17.1%
Sylvo pastoral area	0.2%	4.4%	14.6%	80.0%	16.4%	1.0%	0.0%	5.2%
Eastern Senegal	15.1%	0.1%	6.8%	2.9%	17.0%	0.6%	0.0%	4.3%
River area	1.3%	2.4%	7.4%	4.3%	14.5%	2.6%	0.0%	14.4%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Sources:SAM.

Table 3 describes Senegal's consumer basket structure. Consumption of raw and processed livestock products accounts for almost 8 percent of total consumption among urban; this number is as low as 0.1 percent in some rural areas.

Table 3: Consumption basket structure

Sectors	Dakar	Other cities	Groundnut belt	Niayes area	Southern Senegal	Sylvo pastoral area	Eastern Senegal	River area
Crops	6.96%	8.48%	3.61%	0.23%	1.60%	0.61%	0.20%	0.54%
Fishery	6.38%	5.49%	1.47%	0.15%	0.50%	0.01%	0.04%	0.17%
Crossbred cow	0	0	0	0	0	0	0	0
Traditional cow	0.16%	0.12%	0.04%	0.00%	0.02%	0.24%	0.00%	0.01%
Ovine	0.06%	0.05%	0.02%	0.00%	0.01%	0.00%	0.00%	0.00%
Goat	0.03%	0.02%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Cameline-porcine	0.03%	0.03%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Equine	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Traditional poultry	0.44%	0.33%	0.11%	0.01%	0.05%	0.02%	0.01%	0.02%
Industrial poultry	0.36%	0.27%	0.09%	0.01%	0.04%	0.02%	0.00%	0.01%
Egg	0.52%	0.39%	0.13%	0.01%	0.06%	0.02%	0.01%	0.02%
Raw milk	1.54%	1.16%	0.39%	0.03%	0.17%	0.07%	0.02%	0.06%
Other livestock product	0.24%	0.18%	0.06%	0.00%	0.03%	0.01%	0.00%	0.01%
Processed meat	3.86%	3.78%	1.11%	0.12%	0.39%	0.16%	0.04%	0.13%
Processed fish	2.57%	2.52%	0.74%	0.08%	0.26%	0.10%	0.03%	0.09%
Leather	0.85%	0.61%	0.22%	0.02%	0.08%	0.03%	0.01%	0.03%
Processed milk	0.86%	0.84%	0.25%	0.03%	0.09%	0.03%	0.01%	0.03%
Other industry	35.34%	26.82%	12.07%	1.27%	4.49%	1.49%	1.16%	1.52%
Tradable services	39.81%	23.28%	4.56%	0.59%	1.91%	0.49%	0.16%	0.65%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Sources: SAM.

2.3 Public finance

Government income essentially depends on indirect taxes (70.6 percent), which comprise taxes on sales (53.97 percent) and imports (16.68 percent). Direct taxes represent 20 percent of the government's total income, and transfers account for nearly 9.66 percent.

Table 4: Government income

	Ratios
Direct taxes on income and profit	19.69
Tax on sales	53.97
Import tax	16.68
Transfers from the ROW	9.66
Total	100.00

Sources: SAM.

2.4 Foreign trade

Livestock products are mainly non-tradables in the Senegalese economy (Table 5) and thus their relative weight in imports and exports is weak. By contrast, the processed meat, processed milk, and leather sectors produce tradable goods; 86.5 percent, 39.4 percent, and 31 percent of the production in these sectors is geared toward the international market. Moreover, processed meat, milk, and leather imports supply up to 15 percent, 65 percent, and 40 percent of domestic demand.

Table 5: Structure of foreign exchanges

Sectors	Imports of product ii/Total imports	Imports of product i/Total absorption	Export of product i/Total exports	Export of product i /Production of product i
Crops	5.25%	18.54%	1.54%	4.07%
Fishery	0.36%	70.31%	9.84%	97.63%
Crossbred cow	0.21%	99.4%	0.00%	0.00
Traditional cow	0.62%	29.1%	0.00%	0.10%
Ovine	0.00%	0.00%	0.00%	0.00%
Goat	0.00%	0.00%	0.00%	0.00%
Cameline-porcine	0.00%	0.00%	0.00%	0.00%
Equine	0.00%	0.00%	0.00%	0.00%
Traditional poultry	0.00%	0.00%	0.00%	0.00%
Industrial poultry	0.00%	0.19%	0.02%	1.66%
Egg	0.01%	100.0%	0.0%	100.0%
Raw milk	0.00%	0.00%	0.00%	0.00%
Other livestock product	0.00%	0.46%	0.12%	7.25%
Processed meat	1.84%	72.85%	6.89%	86.48%
Processed fish	1.23%	18.04%	4.59%	34.32%
Leather	0.41%	48.96%	0.30%	31.28%
Processed milk	3.18%	63.85%	1.85%	39.45%
Other industry	78.53%	32.59%	43.99%	14.67%
Tradable services	9.19%	6.13%	30.85%	12.22%
Total	100%	22.62%	100%	15.66%

Sources: SAM.

3. Methodology

In this paper, a recursive dynamic general equilibrium model is built to assess the effects of an artificial insemination program on livestock productivity and economic growth.

3.1 Model Description

The dynamic model of the Senegalese economy has been developed based on a Pep model (Decaluwe, Lemelin, and Robichaud, 2013). This model applies to a small open economy for which world prices are

given and is designed as a set of simultaneous linear and non-linear equations that define both economic agents' behavior and the economic environment in which these agents operate. It belongs to the strand of dynamic recursive CGE literature which implies that agents' behavior is based on adaptive projections rather than on the forward-looking projections that underlie alternative inter-temporal optimization models.

The model integrates seven factors: non-skilled labor, skilled labor, crop capital, cow capital, other livestock capital type, public capital, and land. The institutions selected are households in Dakar, households in other urban centers, rural households in the groundnut belt, rural households in the sylvo pastoral area, rural households in Southern Senegal, Eastern Senegal, Senegal River, and the Niayes area, firms, the Government, and the rest of the world. The value added of the agricultural sector is expressed as a Constant Elasticity Substitution (CES) function of land and a composite factor; this latter is expressed as a Constant Elasticity Substitution (CES) function of composite labor and composite capital. Labor is specified as a CES function of skilled and non-skilled labor, while the composite capital is expressed as a Leontief function specifying fixed shares of public and private capital. The value added of the non-agricultural sector is instead expressed as a CES function of composite labor and non-agricultural capital.

In the recursive dynamic model, it is assumed that current economic conditions, such as the availability of capital, are endogenously influenced by past economic conditions but remain unaffected by forward-looking expectations. The dynamic model is also exogenously updated to reflect demographic changes based on observed or inferred projected trends. The process of capital accumulation is endogenous.

The Senegalese dynamic model is treated as a series of equilibria, each one representing a single year. In other words, the model takes into account dynamic adjustments in simulating artificial insemination and a counterfactual scenario (steady average rainfall). The difference between the economic pattern under artificial insemination pattern and the counterfactual scenario is interpreted as the economy-wide impact of artificial insemination. With regards to closure rules, the ratio of current account to GDP is supposed to be fixed. In terms of dynamic, an increase in imports of a group of goods and services requires an increase in exports of other groups of goods and services, so as to maintain the balanced current account. The exchange rate and inventories are also supposed to be fixed.

3.2 Specific features

A number of features have been added to the model. The stock of sectoral private capital at period t is equal to the stock in the previous period minus capital depreciation, plus the capital accumulated during that period. Private capital accumulated during a period depends on the ratio between the return to capital and the cost of this factor. For a given sector j, the stock of public capital at the period is also equal to the stock of the previous period minus capital depreciation, plus the volume of investment accumulated. Public investment is a complement of private investment. This relation defines the one that links public capital and

private capital in the tradable sector. Pubic investment includes research and development and infrastructure. In the public sector, the investment at period t depends on the available Government income. A specific feature of the model is that artificial insemination is treated as a process of innovation diffusion. Based on Romer's model, one can try to endogenously introduce diffusion of innovation in the livestock sector through artificial insemination. The artificial insemination program, stemming from government R&D efforts, is also viewed as a non-rival good and is quite non-exclusive. For producers who have access to the program, productivity gains tend to be high; hence the program increases sectoral growth. As with the adoption of any innovation, however, the decision to adopt insemination technology involves sunk costs. Expenditures for that purpose are given whereas the percentage of unsuccessful inseminations can be sometime high[1].

The value added of the cow sector, as in other agricultural sectors, is expressed as a Constant Elasticity Substitution (CES) function of land and a composite factor. In this function, the TFP is endogenous and is determined as follows. As AI program relies mainly on budgetary efforts, the rate of increase of insemination is supposed to be a function of expenditures devoted to R&D:

$$\frac{\hat{AI}}{AI} = \lambda RD$$

Thereafter, total productivity factor (TFP) in the livestock sector is supposed to depend to artificial insemination rate of growth:

$$TFP = \frac{\hat{AI}}{AI} = \lambda RD$$

As we distinguish two sub-sectors for the cow sector (cross-bred cows and traditional cows), we suppose that for the cross-bred cow sector, TFP is a function of R&D and of the stock of the total public capital, which creates a positive externality that also affects the sector. Therefore, the TFP depends on R&D and on the ratio between the total public capital and private capital of the cow sector and a scale parameter[2]:

$$A_{cow}^{t} = \overline{A_{cow}^{t}} * \left(\mathrm{RD}_{\mathrm{cow}}\right)^{\lambda} \left(\frac{\mathrm{KDpubG}^{\mathrm{t}}}{\mathrm{KDpriv}_{\mathrm{tr}}^{\mathrm{t}}} \right)^{\theta}$$

[1] It is equal to 44.16 percent for the Senegalese artificial insemination program.

[2] According to policy makers, only 18 percent of the budget of the artificial insemination program has been mobilized, which represents 7.33 million. So the cost of the program is supposed to be 40.72 million. From this total amount, one can increase the TFP by 400 percent though 500,000 cross-bred cows. By producing 107,000 cross-bred cows, this rate is divided by four. So by using production as a proxy, the elasticity λ can be derived from the ratio between changes in production and changes in R&D. It is estimated equal to 0.095. The elasticity of the TFP in the cow sector to the ratio between public and private capital is the same as that used for CAADAP scenarios for Senegal; it is supposed equal to 0.012.

For the traditional cow sector, we also suppose that TFP is endogenous. However, only externalities coming from flows of R&D in the mixed cow sector through the ratio between total public capital and private capital has an effect on TFP.

Another feature of this model is the segmentation of the labor market and the introduction of endogenous unemployment. The wage curve approach developed by Blanchflower and Oswald (1994) is used to model the labor market, in which we assume the existence of unemployment in skilled labor. Workers in this segment are traditionally used in the modern, or formal, sector, where there is relative rigidity in the wage determination. The wage rate evolves according to the behavior of the labor market and the situation described by the wage curve, which shows a negative relationship between levels.

3.3 Data

The dynamic general equilibrium model is built based on a 2005 social accounting matrix (SAM) of the Senegalese economy that focuses on livestock. Data on the program of artificial insemination are collected from Ministry of Livestock.

4. Simulations and Results

The artificial cow insemination program ran from 2008 to 2011 and aimed to produce 500,000 cross-bred cows by the end of the period in order to boost the production of raw milk, processed milk, processed meat, and leather. The total number of inseminations performed was to 28,827 in 2008, 31,885 in 2009, 19,244 in 2010, and 27,203 in 2011.

However, only 107,000 crossbred cows were delivered as an output of the program. Therefore, cross-bred cows represent 15 percent of the total number of cows in Senegal, which is estimated at 3,127,109 on average during the period 2005-2007.

In the simulation that we run, it is supposed that the share of R&D in the flows of public capital in cross-bred cow sector has increased by 307 percent during the period 2008-2011. As the artificial insemination program began in 2008, we assume that there is no shock in the model from 2005 to 2007. Therefore the simulation is run from 2008 to 2011. We also assume that the effects of changes in valued added, factors, economic growth, and household income, as well as changes in prices, will pass through total factor productivity that is a function of R&D. Due to the livestock sector's important weight in the country's agricultural value added and its intersectoral links to processed sectors like milk and meat, any shock to the cow sector can have wide economic effects and feedback effects.

4.1 Sectoral effects

Due to an increase in the total factor of productivity (TFP), the value added of the cross-bred cow sector experienced an increase as soon as the program was implemented at the 5th period. This increase ranged

from 0.25 percent to 0.19 percent. Due to externality effects, the value added of the local cow sector also increased.

The increase of the TFP is due to a raise in R&D. The latter is a part of public investment which is a complement of private capital in this sector. Value added and production increased for all sectors after the implementation of the program, except for ovine and goats.

Table 6: Changes in value added growth w. r. t. the baseline (in %)

Sectors	2005	2006	2007	2008	2009	2010	2011
Crops	0	0.002	0.004	0.003	0.007	0.012	0.016
Fishery	0	0.002	0.002	0.002	0.005	0.006	0.008
Crossbred cow	0	-0.002	-0.004	0.251	0.216	0.187	0.165
Traditional cow	0	0.346	0.729	1.134	1.6	2.11	2.666
Ovine	0	-0.215	-0.468	-0.765	-1.092	-1.461	-1.871
Goat	0	-0.214	-0.465	-0.762	-1.087	-1.454	-1.863
Cameline-porcine	0	0.004	0.008	0.01	0.016	0.022	0.029
Equine	0	0	0	0	0	0	0
Traditional poultry	0	0.001	0.002	-0.001	0.001	0.004	0.006
Industrial poultry	0	0	0.001	-0.001	0	0.003	0.004
Other type of livestock	0	0.001	0.001	0	0.002	0.004	0.005
Processed meat	0	0.045	0.091	0.142	0.195	0.251	0.311
Processed fish	0	0.001	0.001	0	0.003	0.004	0.006
Leather	0	0.002	0.002	0.003	0.007	0.01	0.013
Processed milk	0	0.034	0.066	0.1	0.137	0.174	0.212
Other industry	0	0.003	0.003	0.004	0.007	0.009	0.012
Tradable services	0	0.001	0.001	0.005	0.006	0.008	0.009
Non tradable services	0	-0.002	-0.005	0.014	0.01	0.005	-0.001

Sources: simulations.

The cow sector supplies Senegal's domestic market with six products: traditional cows, cross-bred cows, processed meat, processed milk, raw milk, and leather. Raw milk and raw meat serve as an input for processed milk and processed meat. Thus, as a consequence of increasing cow supplies (both cross-bred cows and local cows), local producers' sales also increased for these six products, mainly for local cows, raw milk, and processed meat.

Table 7: Changes in local sales w.r.t. the baseline (in %)

Sectors	2005	2006	2007	2008	2009	2010	2011
Crops	0	0.002	0.004	0.003	0.008	0.013	0.017
Fish	0	0.003	0.015	-0.003	0.018	0.041	0.061
Crossbred cow	0	0.001	0	0.053	0.047	0.043	0.04
Traditional cow	0	0.144	0.299	0.45	0.628	0.818	1.02
Ovine	0	0.025	0.049	0.071	0.093	0.114	0.134
Goat	0	0.027	0.051	0.075	0.099	0.121	0.143
Cameline-porcine	0	0.004	0.008	0.01	0.016	0.022	0.029
Equine	0	0	0	0	0	0	0
Traditional poultry	0	0.001	0.002	-0.001	0.001	0.004	0.006
Industrial poultry	0	0	0.001	-0.001	0	0.002	0.004
Other type of livestock	0	0.001	0.001	0	0.002	0.004	0.005
Processed meat	0	0.042	0.087	0.13	0.183	0.239	0.298
Processed fish	0	0	0.001	-0.001	0.002	0.003	0.006
Leather	0	0.001	0.002	0.004	0.007	0.01	0.013
Processed milk	0	0.031	0.06	0.091	0.125	0.158	0.194
Other industry	0	0.003	0.004	0.004	0.007	0.009	0.012
Tradable services	0	0.001	0.001	0.005	0.006	0.008	0.009
Tradable services	0	-0.002	-0.005	0.014	0.01	0.005	-0.001
Egg	0	0.013	0.034	-0.002	0.04	0.081	0.12
Raw milk	0	0.088	0.18	0.272	0.371	0.475	0.582

Sources: simulations.

4.2 Impact on the returns on factors

We assume that the cow sector uses a specific type of capital (capprelb). Endowments in terms of this type of capital are more important in the sylvo pastoral rural areas, where raising livestock is the main economic activity. Between skilled and non-skilled labor, the cross-bred cow sector is more intensive in qualified labor, while the local cow sector is more intensive in non-skilled labor. The local cow sector also uses land as a factor, while this factor is weakly used by the cross-bred sector.

Due to an increase in TFP driven by the artificial insemination program, the rate of return of cow capital tends to decrease after the implementation of the program. Wage rates also tend to decrease slightly for

both skilled and non-skilled labor. Due to an increasing value-added in the crop sectors, the rate of return of land and agricultural capital increases, but the effects are quite mixed for non-agricultural capital.

Table 8: Changes in the return on factors w. r. t. the baseline (in %)

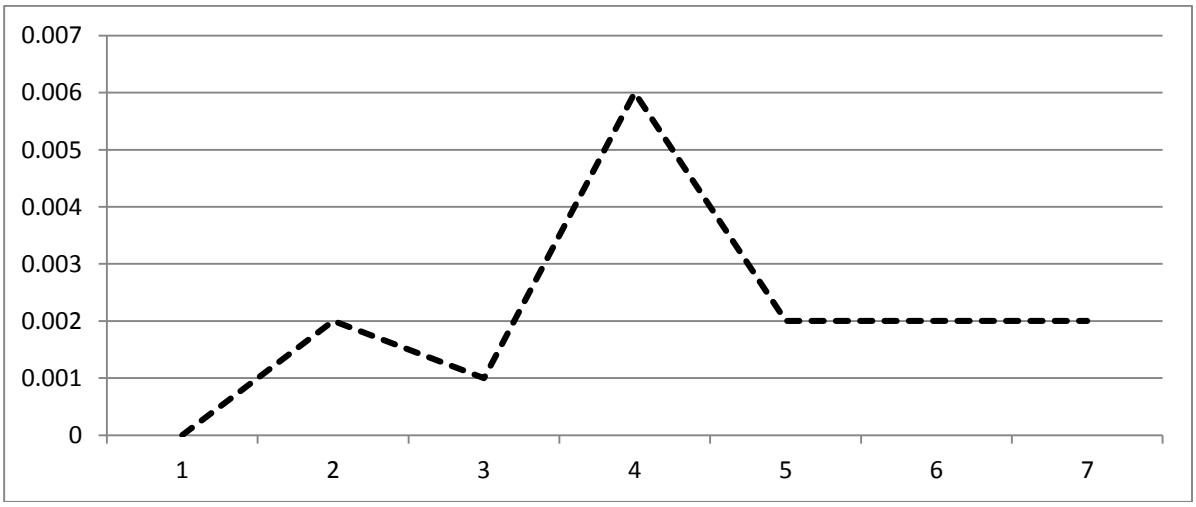
	Agricultural capital	Cow capital	Other livestock type capital	Non agricultural capital	Public capital	Land	Skilled labor	Unskilled labor
2005	0	0	0	0	0	0	0	0
2006	0.002	0.008	-0.147	-0.002	-0.004	0.003	-0.006	0
2007	0.005	0.028	-0.279	0	-0.005	0.008	-0.006	0.002
2008	0.003	-11.876	-0.41	0.003	-0.008	0.006	-0.008	0.003
2009	0.004	-9.448	-0.526	0	-0.01	0.011	-0.006	-0.007
2010	0.005	-7.405	-0.63	-0.003	-0.01	0.016	-0.008	-0.004
2011	0.005	-5.723	-0.734	-0.004	-0.011	0.023	-0.009	-0.002

Sources: simulations.

4.3 Impact on GDP

Changes in GDP growth with respect to the baseline shift from a range of 0.07 percentage points to 0.02 percentage points as soon as the program is implemented. This change in GDP comes from the variation in the cross-bred cow sector's TFP as well as from factor reallocation effects. Thus, the artificial insemination program can have wide effects on Senegal's GDP.

Graph 1: Changes in GDP growth w. r. t. the baseline (in %)



Sources: simulations.

Impact on nominal income and consumer prices

Changes in returns to factors that are redistributed to households affect households' nominal income depending on their endowments. As mentioned previously, capital used in the cow sector is more important

in sylvo pastoral rural areas, where raising livestock is the main economic activity. Hence, returns to this type of capital go mainly to households of these areas. The cross-bred cow sector mainly uses skilled labor, while the local cow sector is more intensive in non-skilled labor. Like agriculture and other livestock sectors, the local cow sector also uses lot of land.

Households will also be affected differently by changes in consumer prices, according to the structure of their basket consumption. Consumer price is an average of import prices and domestic prices, weighted by shares of imports and domestic sales in the composite good. Changes in the price of goods and services consumed will affect households' real consumption. The combined income and price effects will determine a priori the effects of the artificial insemination program on household well-being, measured by the equivalent variation.

All households experienced both a decline and a decline in consumption prices in their district; in some areas, the price effects seem to dominate the income effects. Therefore, well-being increased for some households and decreased for others. Well-being mainly increases for households in the sylvo pastoral rural areas, as well as for urban households (other cities and Dakar) and households in the rural groundnut belt, where several outputs of the cow sector have a relatively important weight in the basket of consumption.

Table 10: Changes in nominal income, consumer prices, and well-being by area w. r. t. the baseline (in %)

Change in nominal income

Period	Dakar	Other cities	Groundnut belt	Niayes	Casamance	Sylvo pastoral area	Senegal oriental	Fleuve
2005	0	0	0	0	0	0	0	0
2006	-0.004	-0.003	-0.006	-0.012	-0.009	-0.009	-0.01	-0.007
2007	-0.004	-0.003	-0.007	-0.021	-0.013	-0.014	-0.016	-0.012
2008	-0.007	-0.006	-0.023	-0.038	-0.057	-0.092	-0.038	-0.041
2009	-0.008	-0.007	-0.026	-0.05	-0.06	-0.093	-0.046	-0.045
2010	-0.008	-0.007	-0.027	-0.062	-0.065	-0.095	-0.053	-0.049
2011	-0.01	-0.007	-0.03	-0.075	-0.07	-0.098	-0.06	-0.054

Sources: simulations.

Change in household consumer price

Period	Dakar	Other cities	Groundnut belt	Niayes	Casamance	Sylvo pastoral area	Senegal oriental	Fleuve
2005	0	0	0	0	0	0	0	0
2006	-0.006	-0.006	-0.006	-0.005	-0.006	-0.033	-0.004	-0.006
2007	-0.01	-0.01	-0.01	-0.008	-0.011	-0.063	-0.007	-0.011
2008	-0.014	-0.015	-0.015	-0.011	-0.016	-0.096	-0.01	-0.016
2009	-0.02	-0.02	-0.02	-0.015	-0.021	-0.128	-0.014	-0.021
2010	-0.024	-0.025	-0.024	-0.019	-0.026	-0.159	-0.017	-0.026
2011	-0.029	-0.029	-0.028	-0.022	-0.031	-0.191	-0.02	-0.031

Sources: simulations.

Equivalent variation

Period	Dakar	Other cities	Groundnut belt	Niayes	Casamance	Sylvo pastoral area	Senegal oriental	Fleuve
2005	0	0	0	0	0	0	0	0
2006	0.002	0.003	0	-0.004	-0.002	0.008	-0.001	0
2007	0.004	0.006	0.002	-0.006	-0.001	0.018	-0.001	0
2008	0.006	0.007	-0.006	-0.014	-0.031	0.005	-0.003	-0.007
2009	0.01	0.012	-0.003	-0.017	-0.028	0.017	-0.003	-0.006
2010	0.013	0.016	0	-0.021	-0.027	0.031	-0.004	-0.005
2011	0.017	0.021	0.004	-0.026	-0.026	0.044	-0.004	-0.005

Sources: simulations.

5. Conclusion and Policy Lessons

The contribution of livestock to Senegal's agricultural growth is highly important, particularly in the sylvo pastoral rural areas. In addition, outputs from the cow sector can have relatively important weight in both urban and rural households' consumption baskets.

The aim of this paper is to assess the effects of an artificial cow insemination program of Senegal. This program was run from 2008 to 2011 and aimed to produce 500,000 cross-bred cows by the end of the period in order to boost the production of raw milk, processed milk, raw meat, processed meat, and leather. However, only 107,000 crossbred cows were delivered as an output of the program.

In this paper, we first build a general equilibrium dynamic recursive model within which we endogenize the total factor productivity (TFP) for the cow sector. For the cross-bred sector, TFP depends on the effort of research and development (R&D) and on the externalities of public capital given by the ratio between private and public capital in this specific sector. Thereafter, the rate of accumulation of R&D is supposed

to be a fixed ratio of public capital in the cross-bred cow sector. For the local cow sector, TFP is a function of the externalities of public capital given by the ratio between private and public capital in this sector. The value-added in those two cow sub-sectors of cow therefore depends on an endogenous TFP.

We then simulate and assess the effects of Senegal's artificial cow insemination program on sectors, factors remuneration, and hence GDP and well-being. We assume that R&D for program coming from flows of public capital increased from 2008 to 2011.

The results obtained show that production of cross-bred and local cows has significantly increased in Senegal. This in turn induces an increase in several products coming from the cow sector, including raw meat, processed meat, raw milk, processed milk, and leather. However, the increase in TFP seems to have a depressive effect on returns to factors, as income for all households tends to decrease. On the other hand, consumption prices also decrease for all households, and the price effects seem to overcome income effects. Households in the sylvo pastoral rural areas, urban areas (Dakar and other cities), and the rural groundnut belt benefit from this program, while households in Southern Senegal, Eastern Senegal, Senegal River, and the Niayes area see decreased well-being.

While the program aimed to cover 15 percent of Senegal's total cow population, it effectively only covered three percent. Thus, scaling up the program poses a challenge. A related challenge is reduce the number of areas that do not benefit from the program; this could be done by increasing the program's scope to go beyond the original goal of 500,000 cow in order to enhance the program's income effects. It could also by accomplished by the development of other livestock sectors like poultry, ovine, goat, and equine sectors.

A broader artificial livestock insemination with better management practices could be a strong policy tool to boost the contribution of livestock to Senegal's agricultural GDP growth and to enhance the well-being of households throughout the country.

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