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THE ROLE OF SYSTEMS OF INNOVATION IN ADAPTING TO CLIMATE CHANGE: THE CASE OF THE KENYAN COFFEE AND DAIRY SECTORS[1]

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ABSTRACT

Research on sectoral systems of innovation has paid little attention to adaptation to climate change, notably in agriculture. This article, therefore, explores the role of systems of innovation in adapting to climate change. It focuses on two case studies in Kenyan agriculture, i.e. the coffee and dairy sectors, which differ in terms of stakeholders and institutional setups. In the coffee sector, the actors' system is highly centralized and the system of innovation is oriented towards technology development. In contrast, the dairy sector consists of a diversity of actors, and its system of innovation is based on institutional building and marketing. The capacity to innovate and adapt, therefore, depends on institutional arrangements in addition to technology development, suggesting that the dairy sector in Kenya could be an example for the coffee sector.

Keywords: Climate Change, Coffee Sector, Dairy Sector, System of Innovation, Central Kenya

JEL Codes: O30, O31, O33

The impacts of climate change on economic growth are still an issue for debate. Some consider that climate change could be an opportunity for economic growth, while others argue that it will lead to a slow-growing economy, or even de-growth. However, this debate must take into account regional differences: in the colder regions of the Northern Hemisphere, climate change could have a positive effect on production, while in the tropics it is expected to substantially reduce economic growth (IPCC, 2014). In Africa and Latin America, for instance, maize production is expected to decline, which would result in a loss of $2 billion per year as of 2055, compared to current production (Jones, Thornton, 2009).

These impacts will be more significant as Greenhouse Gas (GHG) Emissions increase. However, adaptation strategies are necessary in every case. Decisions on adaptations need to take into account the everchanging climate because of two main reasons: first, future uncertainty challenges the use of available technologies as the latter are designed for current challenges (Iglesias *et al.*, 2011). Second, the rate of climate change calls for flexibility in new infrastructural development (Hallegatte, 2009), technical systems and economic organizations. In particular, the impact on agriculture varies depending on farming systems or sectors (Touzard *et al.*, 2015), which differ in sensitivity and exposure to changes.

The capacity of climate change to adapt depends on many factors, such as market dynamics, private and public investment in R&D, policy and institutions (Hallegatte, 2009), or even cultural aspects (Dunlap, Brulle, 2015). A key factor is the capacity for cooperation between actors in regions and sectors (Boyer, 2016). Touzard (2015), for example, reports that climate change has a systemic impact on both regional vineyards and wine value chains, calling for cooperative solutions between actors at these two levels. Hence, adaptation capacities depend on the type of sector, and actors' interaction and coordination, notably in agriculture (Soussana, 2013). In rainfed crop production, adaptation comprises practices such as adopting drought-resistant varieties or intercropping (Teucher *et al.*, 2016), while alternative feeding strategies or building insulation are promoted in the livestock sector (Seo, 2010).

Until now innovation studies have emphasized the role of innovation in producing economic and social changes (Van Lancker *et al.*, 2016; Temple *et al.*, 2015), in particular in each sector, where knowledge and technology, the structure of demand, institutions and firm characteristics are different (Malerba, 2002). The concept of the Sectoral System of Innovation (SSI) is thus proposed in order to analyze this set of factors, which can strongly determine specific trends in innovation in each sector, with possible effects on economic performance and adaptation to global challenges such as climate change (Malerba, 2007). Empirical studies, however, insufficiently take into account sectoral differences in innovation for climate change adaptation, and the role that an SSI could play (Touzard, 2014).

This article therefore aims to analyze the roles of SSI in the adaptation of sectors to climate change, focusing on the coffee and dairy sectors in Central Kenya. It provides an answer to two questions: (1) what characteristics of the systems of innovation are particular to each sector in the process of adaptation to climate change? (2) How do such characteristics affect the adaptation process and competitiveness of the sectors?

We mobilize the SSI approach in order to explore conditions of adaptation to climate change in the coffee and dairy sectors, which are similar in terms of farmers' objectives and shifting historical fortunes, but are different in terms of marketing, socio-political and technical characteristics, and policy. We would contribute i) to the SSI literature on the agricultural sector, that is still scarcely studied (Touzard *et al.*, 2015), and ii) to research on adaptation to climate change by focusing on the role of SSI. The next section discusses the use of the SSI approach. In section three, we present the method which combines focus groups' discussions and surveys of actors in the coffee and dairy sectors in Kenya. In section four we provide the results and finally, in section five, we discuss our results.

USING THE SECTORAL SYSTEM OF INNOVATION APPROACH TO ANALYSE ADAPTATION TO CLIMATE CHANGE

The concept of SSI basically provides a multi-dimensional, integrated and dynamic view of specific economic sectors, including different structural components and a set of actors carrying out market and non-market actions (Malerba, 2002; Edquist, Chaminade, 2006). The key structural components of SSI are the knowledge base and the learning process, the technological base, specific institutions (rules, norms) and the evolution of demand, while the agents in the SSI are individuals, firms and non-firm organizations who are involved at various levels of the production and innovation processes (Malerba, 2007). These actors have specific models of interaction, interdependencies and links, which depend on the evolving structure of each sector.

Sectors provide a key level of analysis for economists, policy makers or firm managers to analyze basic firm structure and concentration in the literature of industrial economics. However, Malerba (2002) argues that SSI approaches are much richer empirically in analyzing knowledge dynamics, learning competencies, networks, and interactions. Moreover, while the SSI framework has been mobilized to analyze economic development and the adoption of new technologies in many industrial sectors, there has been little explicit study of agriculture using this framework. In agriculture, a first line of research refers to the notion of a system of innovation (Touzard *et al.*, 2015), promoting the specific notions of an "Agricultural Innovation System" (AIS) or an "Agricultural, Knowledge and Innovation System" (AKIS) (Klerkx, Jansen, 2010), which shares many aspects of Malerba's SSI approach. But SSI, AIS or AKIS have so far not been mobilized to analyze climate change adaptation in agriculture (Boyer, 2016). This article, therefore, makes an initial attempt at developing a framework to apply the concept of SSI to analyzing adaptation to climate change in the agricultural sectors and sub-sectors. It assumes that their performance and capacity to adapt depend on how the actors and institutions make up the system. Evolutionary concepts, such as interactions, learning, knowledge and competence, are also included in our proposed framework, in addition to other notions coming from industrial economics, innovation economics or the literature on adaptation to climate change in agriculture (Soussana, 2013). Our approach considers three analytical dimensions:

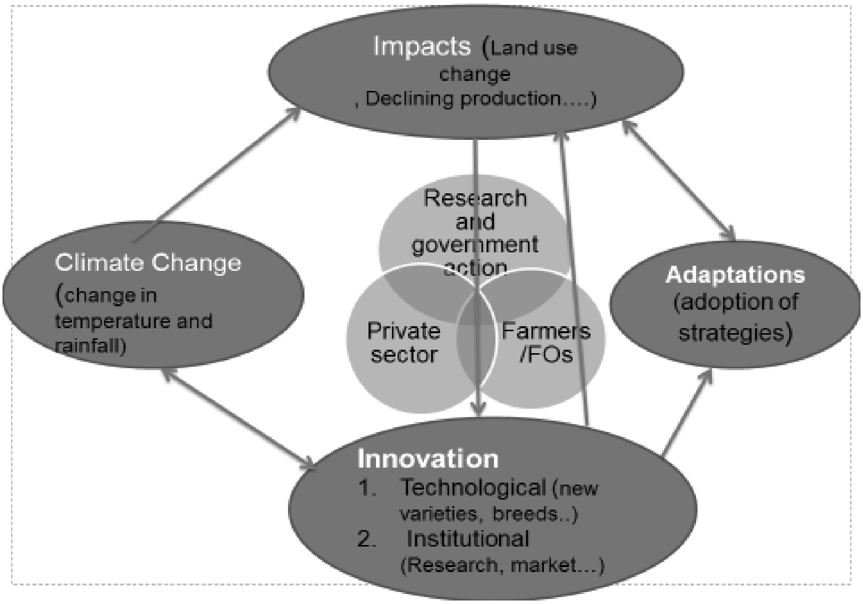
The first dimension is understanding of the sectoral changes, which result from the combination of internal and external factors. Internal factors of change rely on the evolutionary life cycle of the sector (Utterback, 1994), the emergence of an internal crisis, the endogenous development of innovative culture, or the expression of the economic interest of actors (Hallegatte, 2009). External forces are potentially diverse (political, economic, technological, ecological…), one of which may be climate change. Climate change may be considered as a double pathway: an impact pathway and an adaptation pathway. From the impact pathway, climate variability and change may increase the frequency of drought and thus impact the innovation to adapt to changes (Figure 1). Due to the direct relationship between crop production and climate, agriculture is the sector most affected by climate change (Howden *et al.*, 2007; Angeon, Bates, 2015). Hence, the link between the impacts of climate change and innovation to adapt will strongly determine the dynamics of agricultural sectors, directly through the evolution of productivity, and indirectly through changes in land use (Hannah *et al.*, 2013). As temperature and rainfall patterns are expected to continue to change, the impacts will be more severe.

The second dimension of our SSI approach focuses on the interdependencies between different sectors and their actors. The boundaries of sectors are not fixed but dynamic, which provides a mechanism of emergence, growth, changes and innovation (Touzard, 2014). For example, over the last 35 years, coffee in Kenya has moved up to higher altitudes, while food crops have been grown at the altitude once reserved for coffee production (Asayehegn *et al.*, 2017). Land use competition between sectors creates a mechanism of interaction among actors. In the agroforestry coffee systems of Kenya, the emergence of the dairy sector generates new interactions between actors, creating new links between coffee, tea and dairy systems. In such cases, links and boundaries could be competitive or complementary. The links and interdependencies among actors could be within a sector and/or across sectors.

The third dimension is the characterization of the innovation and adaptation processes. Innovations to adapt to climate change may be technological, such as the development of new varieties and new breeds, or institutional, such as implementing new rules, norms or organizations that improve collaborations to reduce the impacts of climate change (Figure 1).

The development of new cultivars of cowpea in the Sahelian West Africa, for example, helped farmers to cope with the climate challenges they experienced (Chhetri *et al.*, 2012). In East and South Africa, scientists developed high yielding maize varieties, with the objective of reducing vulnerability to drought (Fisher *et al.*, 2015). New agronomic practices are another line of innovation for adaptation. Cropping system diversification, conservation tillage, and new fertilizer management have proved to be sustainable adaptation practices, increasing farmers' income and reducing agronomic risk (Teklewold *et al.*, 2013). Institutional innovation may also exert influence on both the impacts of climate change and adaptation (Figure 1). For example, the adoption of new varieties depends on both upstream and downstream organizations (dissemination of varieties and credits vs access to market). New institutions may also improve actors' interactions in providing solutions for adaptation,

Figure 1 – Conceptual model illustrating interaction between climate change impacts, innovations and adaptation to climate change



Source : Authors' own representation of concepts

by improving knowledge-sharing and inter-organizational learning, complementary resource development, capacity building, and efficient governance (Dyer, Singh, 2012). In agriculture, institutional innovation and collaborative projects involving farmer's organizations play a key role in the dissemination of climate-smart innovations and practices (Cerdán *et al.*, 2012). A study from the dairy sector in Kenya, for example, shows that farmers' innovation is driven by the development of new technologies of information, new services for input access, and infrastructural facilities for delivering their products to markets (Schreiber, 2002). The performance and adaptation of agricultural sectors, however, depends on the roles and performance of multiple actors, their interaction, and co-production of knowledge (Klerkx, Nettle, 2013).

DATA AND METHODS

Coffee and Dairy Sectors in Kenya Facing Climate Change

The study area, Murang'a County in central Kenya, is one of the areas with diversified physical environments and an extreme climate. It is made up of three agro-ecological zones, each corresponding to a different altitude range (low, middle and high) and farming systems (food crops, coffee and tea). The lower altitude zone of the County, which is a food crops zone, has a semi-arid climate with a high potential for drought, while middle and high altitudes have potential for coffee and tea production, respectively. Dairy production is also an emerging business across all altitudes. Climate change is, however, strongly impacted in the study area. Long-term rainfall has declined and the temperature has increased; previous potential coffee areas are transformed into marginal coffee or food crops, and favorable weather zones are transformed into arid and semi-arid zones.

Historically, coffee production was one of the main income-generating activities for rural households in Kenya (Carsan, 2014). Following the "Lancaster House Conference" after independence, most of the large-scale coffee farms were sold to local elites (Ratten, 1993) and local indigenous people were encouraged to invest in coffee. Due to the expansion of plantations and the attention given to coffee by farmers and the government, the sector grew at an annual rate of 6.6% until 1987 (FAO 2013). However, since 1988, coffee production has declined by 62% (FAO 2013). During this period, coffee has moved up from the lower altitudes, where it has been replaced by dairy and food crops, for two reasons: First, warmer temperatures and erratic rainfall (Asayehegn *et al.*, 2017) resulted in the transformation of potential areas into semi-arid zones, where a minimum unit temperature increase is subjected to a yield decline of 137 kg per hectare (Craparo *et al.*, 2015). Second, climate change encouraged the infestation of Coffee Leaf Rust (CLR) and Coffee Berry Diseases (CBD), causing the transformation of previous potential coffee-growing areas into marginal coffee or food crop areas (Jaramillo *et al.*, 2014).

There were three main periods in the development of the dairy sector in Kenya, i.e. the period of steady growth (before 1990), disruption (1991-2002), and the period of revival (since 2003). During the period of steady growth, indigenous smallholder farmers were encouraged to develop dairy production through training, infrastructural development, and service delivery. Annual milk production grew from 75 million liters in 1964 to 392 million liters in 1990. During the period of disruption, dairy production declined from 359 million liters in 1991 to less than 150 million liters in 2002, due to the absence of an efficient market and supply system. During the revival period, the dairy sector experienced a sharp increase in the volume of production, reaching over 4.1 billion liters in 2014 (FAO, 2011).

Methodological Approach

Three types of data were used for this study: village and household data collected during nine Focus Group Discussions (FGDs), surveys with 240 household farmers, and semi-directive surveys with other key stakeholders in the dairy and coffee sectors.

The FGDs were conducted with twelve farmers per group. FGD members were selected by local leaders after developing different criteria such as farming experience, the extent of knowledge about the village, diversity of farming practices, and the perception of climate change. We stratified the sample proportionally to the production systems. We then made a random selection to obtain the first farmer from the list, and we then calculated the sampling unit for a list of sample farmers. The selection considers three groups: i) coffee-specialized systems, including the household production of coffee at a high rate of intensification, ii) coffee-dairy diversification, where either the household focuses on both systems, or the household's farm income is almost equally from coffee and dairy, iii) dairy-specialized systems, where at least 80% of farmers' income is from dairy.

The household survey was conducted via face to face interviews during May-October 2015, with heads of households. Farmers were asked about general farm and household characteristics, perceptions of climate change, means of livelihood and income types, the kinds of innovations they have introduced, where they had obtained the necessary information, assistance, materials, and finance, and the contribution of different actors to farming. This helped us to characterize the coffee and dairy farmers and understand how the systems of innovation in the coffee and dairy sectors are organized.

Data about other stakeholders were collected using individual semi-structured interviews with actors of innovation networks, who also shared their own experiences. A total of 23 such interviews were conducted with senior experts, technicians, managers, and heads of the following stakeholders: research, extension, private marketing, processing and input dealers, NGOs and CBOs, ministries: questions focused on which services each of them provided to farmers, and how they supported farmers.

The analysis of climate change trends used the farmers' perception and historical climate data. The statistical significance of the trend analysis was performed using the Mann-Kendall test of significance. To analyze the contribution of different actors to the development of the sectors, a six-scale measure (5 = very high contribution, 0 = no contribution) was developed to analyze the views of farmers and stakeholders towards actors' contributions.

RESULTS

Technological and Institutional Innovations to Adapt to Climate Change: A Case Study from the Coffee Sector of Central Kenya

Developing Disease-Resistant Coffee Varieties

Between 1963 and 1987, national coffee production rose dramatically from 34,000 to 140,000 metric tons, benefiting from two technological innovations. In 1963, local farmers were encouraged and supported to use a new technical system that included fertilizer and cultural practices such as pruning, in order to increase yields. The second technological change was the introduction of pesticides in the mid-1960s to prevent frost, Coffee Berry Diseases (CBD) and Coffee Leaf Rust (CLR). Inputs and management supports were provided by the government directly through the cooperatives. In order to further improve production and quality, the Coffee Research Foundation (CRF) developed new disease-resistant varieties during the 1970s, in 1980 delivering a new variety called "*Ruiru 11*", which was disseminated to farmers from 1985 onwards.

However, this SSI of developing new varieties and disseminating new practices and pesticides failed to increase coffee production, or even maintain the level of production. For example, annual coffee production declined from 140,000 to less than 50,000 metric tons between 1988 and 2011, and production per hectare was reduced from 735 to less than 253 kilograms.

The claim that climate change impacted coffee production is based on the evidence that:

- Analysis of long-term climate data showed that rainfall has declined and that the temperature has increased (Table 1). This caused previous potential coffee-growing areas to be transformed into marginal coffee or food crops,
- Farmers' perceptions of changes indicating seasonal and weather patterns were changed (Figure 2). These arguments support the interpretation that the changes in coffee production noted above were induced by climate change, and that SSIs in the coffee and dairy sectors were able to tackle to the current challenges of climate change.

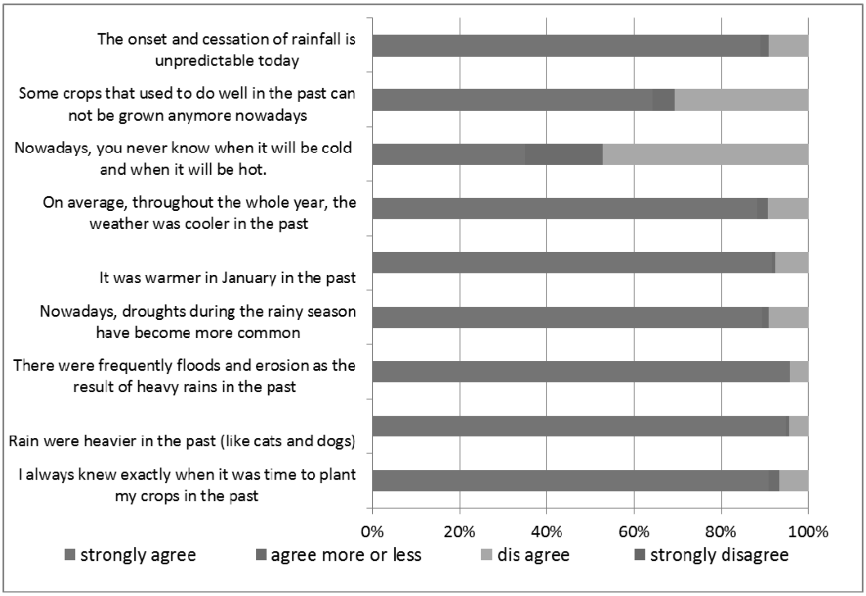
The results from our FGDs converge to show that: i) institutional conditions and extension services were inadequately taken into account in this dissemination and learning process, and ii) that climate change modified the conditions of technical innovation, and was not considered by organizations

Table 1 – Mann-Kendall test of significance of change in temperature and rainfall

Variable	Mann-Kendall's tau	p-value	Sen's slope	Mean	SD
T Max	0.503	<0.0001**	0.043	25.75	0.80
T min	0.509	<0.0001**	0.032	14.19	0.41
T inter annual variability	0.592	<0.0001**	0.037	0.033	0.56
Rainfall	-0.334	0.0040**	-17.100	1179.00	411.50
Significance level (%): 5					

**indicates statistical significance at 5% level
Source: Data source: Kenya Meteorological Department

Figure 2 – Farmers' perception of climate change in Central Kenya



Source : Authors' survey data, 2015

of the coffee SSI. In relation to variety selection, farmers were confronted by two main challenges. First, the new varieties, which farmers call "*heavy feeders*", meaning the new coffee varieties, particularly *Ruiru 11*, which requires higher doses of fertilizer and frequent watering. This is linked to their physiological characteristics, where the root system is shallow. Second, the old varieties are effective for nutrient intake, due to their deep root system, but are highly sensitive to CBD and CLR, where farmers were forced to invest in purchasing chemicals.

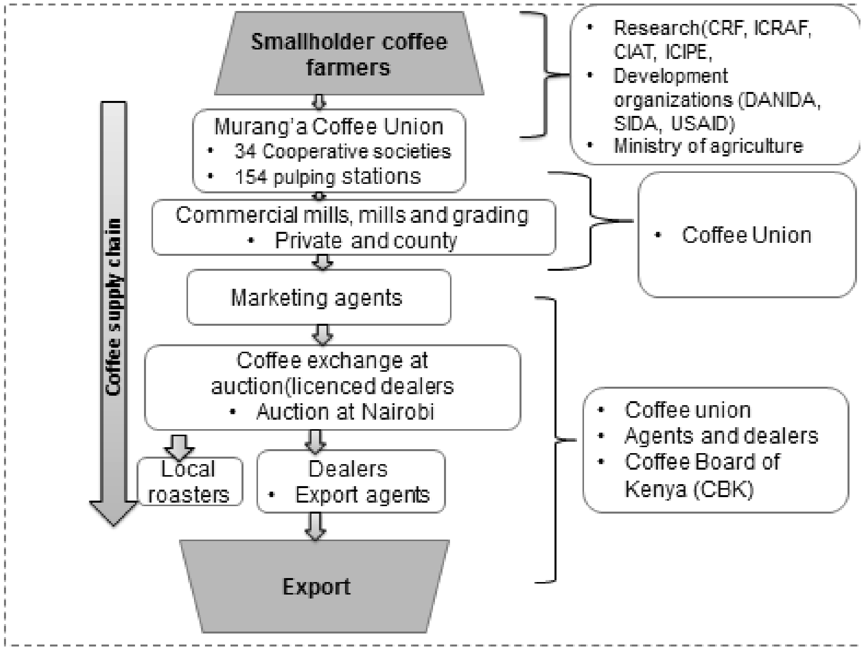
Institutional Innovation in the Coffee Sector

We classified the actors in the coffee sector SSI in three main categories. The first category includes the national and county government organizations, which were the direct administrative bodies for the sector. The second category covers research and education institutions, such as the Kenya Agricultural and Livestock Research Organization (KALRO), international research institutions linked to CGIAR (ICRAF, CIAT), ICIPE, CIRAD, or joint research programs and projects with the AU and the EU, etc. These organizations developed research projects for the Kenyan coffee sector. The third category brings together development organizations and community-based organizations such as DANIDA, AgroproFocus, SIDA, and USAID. Figure 3 shows two main results from the surveys with these three categories of the coffee sector. First, the coffee SSI is organized around a long value chain with few actors in the marketing system (an oligopolistic structure) and a focus of the research and development organizations at the production scale. Second, the interactions and collaboration between the different actors in the coffee sector appeared weak, and dominated by business and administrative links.

Upstream, the coffee union was the monopoly institution providing financial, administrative and technical services until coffee liberalization in 1992. It was mandated to supply inputs and control the application of rules and regulations on coffee production and supply. After liberalization, the Coffee Board of Kenya (CBK), which was the regulatory body, became responsible for defining marketing rules. The coffee union and CBK had a direct link with the government institutions, CRF, milling companies (coffee processing), and auction and export agents (Figure 3). Downstream institutions and actors such as societies, local government agents (Ministry of Agriculture, cooperatives), national and international research centers (CRF, KALRO, CGIAR), and community-based development organizations, were loosely linked to upstream actors. These unconnected and uncoordinated SSIs created an opportunity for private business-oriented actors to have higher input prices.

According to our findings, these led coffee farmers in the community to follow four main strategies to adapt to the challenges they encountered. The first strategy was a continued specialization in coffee production by investing in inputs and chemicals. The second strategy was to intercrop food crops and fodder in coffee farms, which reduced coffee production. The third strategy was abandoning coffee management and shifting their source of livelihoods to off-farm and non-farm activities. And the fourth strategy was completely uprooting their coffee in order to plant other food crops and fodder for their livestock.

Figure 3 – Smallholder coffee supply chain and actors' interaction in Kenya



The findings from the FGDs also indicated that shifting from coffee to other activities, which caused land use change, was mainly due to challenges encountered in service provision, and the weak role played by actors in the SSI. Agronomic and breeding activities were provided by downstream actors such as the CRF and other research organizations, which was loosely connected and coordinated to upstream actors such as the Coffee Union and CBK.

Innovation in the Dairy Sector to Adapt to Climate Change in Central Kenya

The SSI in the development of the dairy sector was mainly based on three broad categories of change: technological development, extension and education on best practices for keeping dairy animals, and institutional building for marketing channels (Figure 4).

Technological Innovation in the Dairy Sector

The focus of technological innovation was the generic improvement of livestock breeds and the sanitary supervision of livestock. It also involved using new grass, shrubs and commercial feed in order to solve the acute feed shortage linked to climate change. For its part, extension and education was mainly developed by applying a business-oriented private sector approach. The breeding materials, health services and innovative new feed systems were primarily developed at research centers or directly adapted from abroad.

Originally, the local cow breeds in Murang'a were the Zebu, with a medium performance in meat and milk productions. As the farmers' objective was mainly to improve milk production, continuous crossing of the best traditional breeds was carried out, leading to higher milk performance crossbreed cows. Artificial insemination of improved breeds was used and farmers experienced the requirements of the new breeds' in terms of feeding and housing. The other technological innovations in the dairy sector were mainly dedicated to improving safety and milk quality, such as the installation of 35 dairy cooling plants (each with 5,000 liters of capacity) in the milk shed localities.

Institutional Innovation

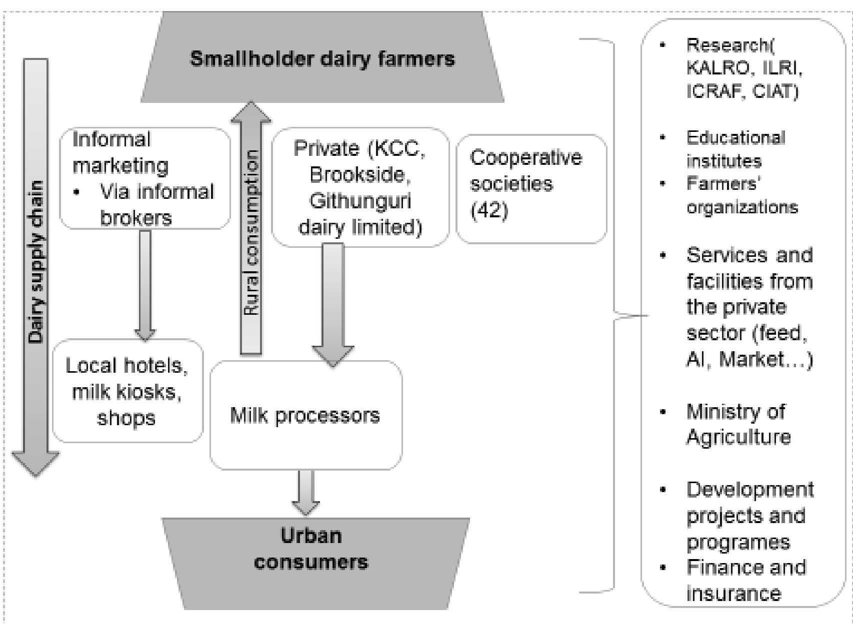
Kenya Cooperatives Creameries (KCC), equivalent to the Coffee Union, was established in 1925 to support the production, marketing and processing of dairy and dairy products as a monopoly agent. The Kenya Dairy Board (KBD), equivalent to the CBK, was created to regulate the dairy sector. There were essentially three periods in the SSI in the dairy sector. During the first period, a cattle breeding was fairly well organized and subsidized by the government. Breeding materials and artificial insemination were effectively used to upgrade breeds. KCC continued to be the sole agent for marketing and processing, protected by policy. During the second period, the position of cooperatives and the KCC weakened after liberalization of the sector. Farmers' milk delivery to KCC and other cooperatives declined due to irregular payments and delays in response to the liquidation of the KCC.

As a consequence of the liberalization of the dairy sector, the services previously delivered by the government stopped. Public breeding and veterinary services were cut back and artificial insemination services became inadequate. Indeed, the private sector was insufficient and not able to develop the insemination service, as well as the feeding function for the whole sector. Around the middle of the 1990s, self-help groups and informal agreements emerged. Deregulation of milk prices created an opportunity for different actors to participate in milk marketing. Three options for milk marketing thus co-existed: the KCC as a government agent, private companies such as Brookside Dairy Limited, and informal channels (Figure 4).

During the last period, a new impetus corrected previous administrative and technical failure. Alternative feed sources such as drought-resistant grasses were developed and new commercial feed companies emerged. Driven by increasing national demand for milk, prices increased, providing farmers with greater motivation to increase their production, in a new institutional context which allows the stable availability of feed for domestic and commercial opportunities. The KCC was privatized and county cooperatives emerged in a new way.

Five categories of actors played a role in the dairy SSI (Figure 4): i) government development agencies; ii) national research organizations, particularly the Kenya Dairy Research Institute and the Kenya Beef Research Institute, and international research organizations (ICRAF, ILRI, CIAT, CYMMIYT, ICIPE…), or joint research programs with the AU or the EU, iii) development and community-based organizations such as DANIDA, TechnoServe, SIDA, USAID and others, iv) organizations from the private sector, such as Brookside, the KCC, Guthunguri, and v) finance institutions, both public and private, such as banks and microfinance institutions.

Figure 4 – Supply chain of milk and actors' interaction in Murang'a County, Kenya



Regarding actors' interaction in the dairy SSI, among the government agencies KDB continued to control the quality of, and to regulate, dairy products from both the cooperatives and private firms. The dairy SSI also included demonstration and trail fields for higher education institutions such as the University of Nairobi, Kenyatta University, and Egerton University, as important research actors. National and international research organizations participated in collaborative programs on breeding, production, feeding and marketing. The EADD program was the best example of a program implemented by a consortium of Heifers International, ILRI, dairy cooperatives, TechnoServe, the African breeders' services, and ICRAF, but also private dealers and banks had been providing credits to R&D initiatives and marketing organizations, including smallholder cooperatives. This kind of coordinated action opens up the options for farmers in terms of input supply, financial support and marketing access. Access to, and management of, feed results from coordination between private feed companies and dairy training institutes. Market arrangements and contract agreements were implemented between the County government, private milk processing companies, and dealers. Access to insurance for cows was also one of the agreements included in the package.

Comparison of the Contributions of Actors in Adaptation to Climate Change in the Coffee and Dairy Sectors of Central Kenya

Our results show that the coffee and dairy SSI differ in both their structural components and the actors' contribution to innovative and collaborative solutions in each sector. Coffee farmers were less supported in their access to material and inputs, compared to dairy farmers. In the coffee sector, the cooperative societies, the County and the national government participated in the provision of material and input, although the provision was not sufficient (Figure 5a). In the dairy sector, the cooperatives, financial organizations (banks, credit and insurance companies), upstream and downstream private firms (input dealers, market agencies), and international research institutes (CGIAR centers, ICIPE) collaborated on input and material supply.

Access to financial and credit services also differed according to each SSI. In the coffee sector, cooperatives and private agents were the main actors (Figure 5b), although this was not satisfactory, while dairy farmers were adequately served by a wider range of financial and credit institutions, such as government, cooperatives and farmers' federations, private suppliers and buyers, and pure financial agents (banks and insurance companies)

(Figure 5b). The power imbalance among the actors also affected interactions and performance in the two sectors. For example, coffee was under the "political control" of the County and the national government, while the dairy sector was driven by a more distributed power structure.

Regarding market access and facilitation, the cooperative union was the sole and autonomous organization for processing and selling coffee on behalf of the farmers, but private marketing agents at the auction remained powerful actors (Figure 5c, Figure 3). Coffee export marketing was done by auction through an agent hired by the cooperative union (Figure 3). Prices were controlled by the top actors in the chain (exporters), and farmers were price takers, with a payment term of at least six months. Consequently, the asymmetry of information in the value chain benefited the actors in the auction and the union, while farmers were disadvantaged and knew hardly anything about quality requirements.

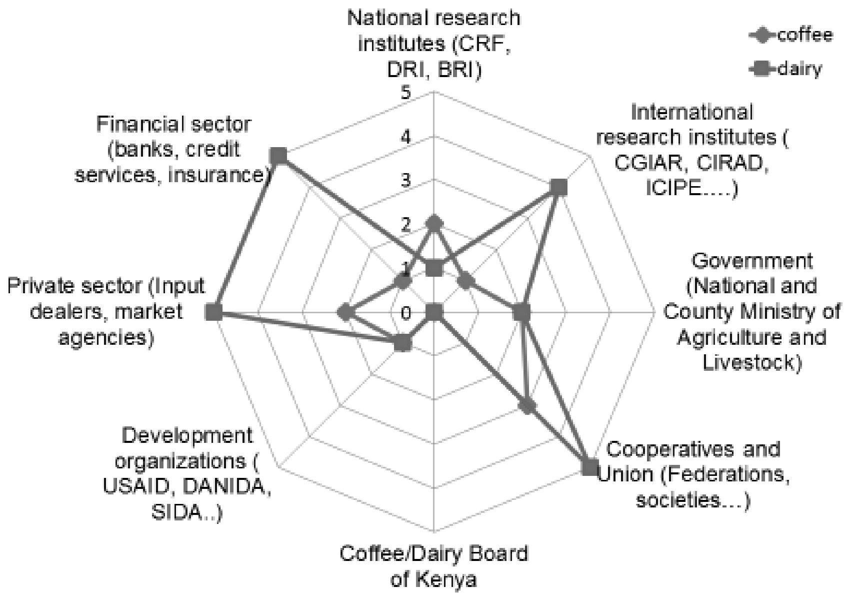
In the dairy sector, cooperative unions and federations, private market agents, development organizations (USAID, Technoserve, SIDA), and international research institutes were involved in facilitating farmers' access to the market (Figure 5c, Figure 4). These actors were more equally distributed throughout the value chain, resulting in more transparency, and both competition and cooperation. All the dairy buyers organize and register farmers looking for improvements in production, input service, and marketing.

Finally, our results on the knowledge base and learning process of the two SSIs showed two contrasting situations: in the coffee sector, CRF, the cooperatives and farmers' federations were the primary sources of information and knowledge for coffee farmers, while there was a limited contribution from international research institutes, county and national governments, and other development organizations (Figure 5d). In the dairy sector, actors such as cooperative unions and farmers' federations, the national and county governments, international research institutes, financial institutions, private suppliers and buyers and development organizations were all providers of knowledge and information (Figure 5d). The coffee SSI was thus narrower and was separated according to the different stages of the value chain, whereas the dairy SSI contributed to a more complex, diversified and extended learning process.

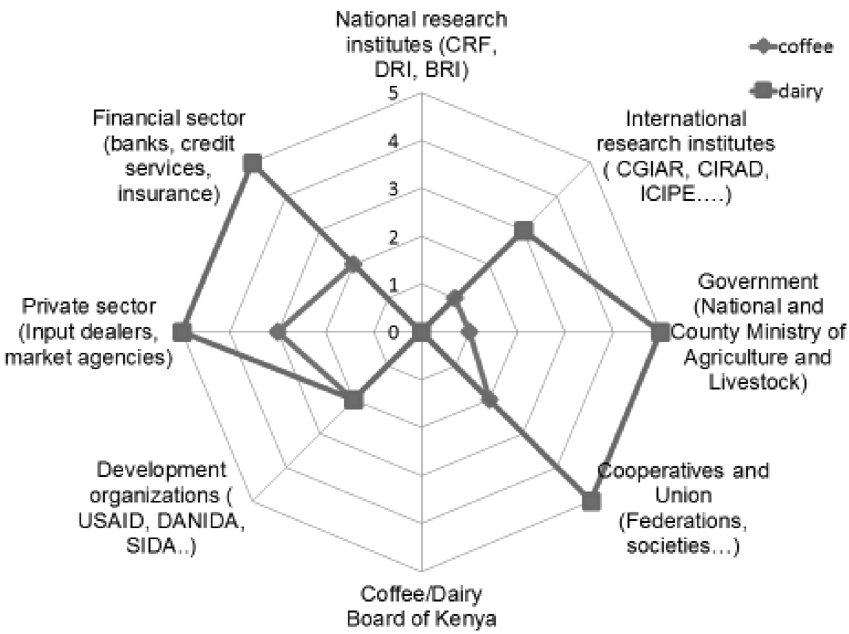
The main question here is: what were the consequences of the SSI in the coffee and dairy sectors for adaptation to climate change? Thus, differences in structural arrangements and the interaction of the actors in the coffee and dairy SSI brought about different ways of farmer adaptation to climate change and adaptive capacity. According to results from the FGDs, coffee

Figure 5 – Actors' contribution towards the development of the coffee and dairy sectors

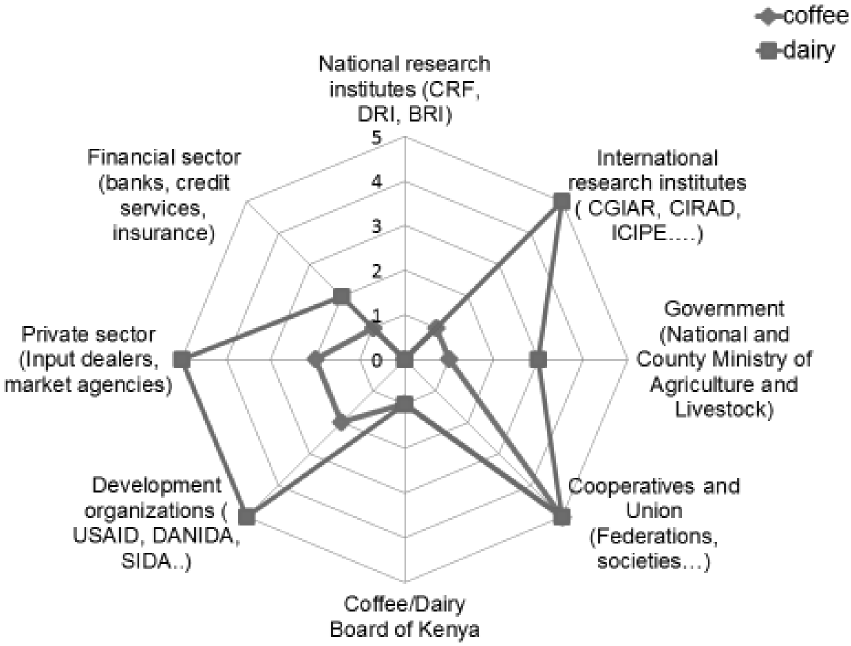
a) Contribution Input/ Material Supply



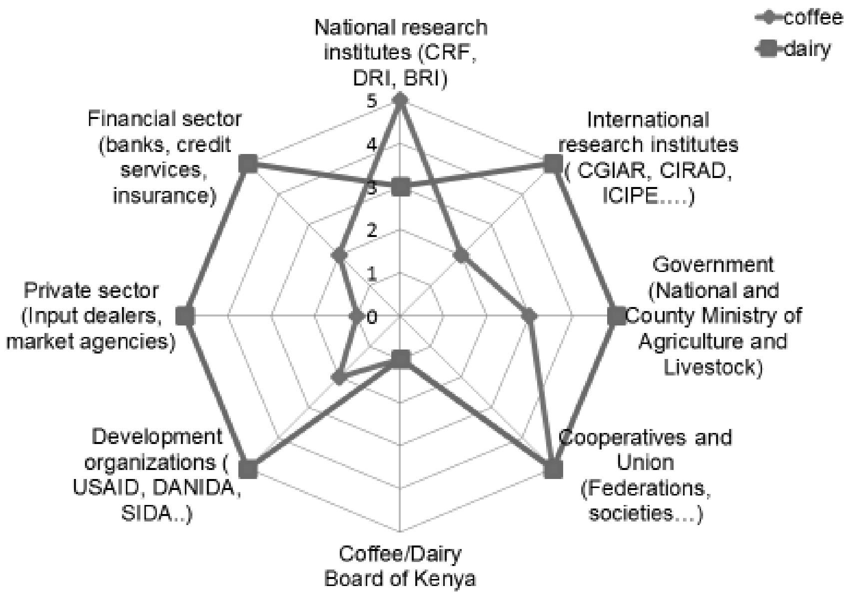
b) Financing and Credit Service



c) Market Access and Facility Arrangement



d) Knowledge / Information Provision



Note: 5= very high, 4=high, 3=medium, 2= low, 1=very low, and 0=no contribution at all farmers adapt to the changes either through diversification of enterprises, such as diversifying into food crops and dairy farming, while dairy farmers specialize in investing in external input and feed. This is connected to the functions and contributions of the SSIs of the different sectors.

DISCUSSION AND CONCLUSION

Macro level agreements, such as the UNFCCC Paris agreement, should be designed to encourage debate on how to tackle climate change through the notion of SSI, for both technological innovation and marketing issues. Technological innovation is indeed important, but this is not the only requirement. Enabling an SSI where some technological innovations contribute to adaptation to climate change should be a priority area for action. In the coffee and dairy sectors of Central Kenya, before market liberalization, the input delivery and marketing system was organized through monopoly cooperative agents. The two sectors experienced a decline during the early years of liberalization, but later they tended to take different directions. While the coffee sector has continued to decline, and has entered a full recession, the dairy sector flourished. The main idea of this discussion is, therefore, to understand why these two sectors, and their SSIs, took different trajectories, and what these evolutions bring in order to understand and act upon farmers' adaptation strategies to climate change.

Three main reasons contribute to the two sectors taking divergent trajectories. First, the coffee SSI continued to push technological innovations, such as disease-resistant varieties, following a very top-down process focused on the production stage, whereas the dairy SSI was more driven by the demand side and involved various stakeholders in the learning process. Second, the two sectors followed different value chain policies: in the coffee sector, input and services were left to private firms, with less attention to farmer empowerment, while the marketing of coffee is based on a cooperative monopoly influenced by powerful private export actors at the top of the chain. The dairy sector, on the contrary, was fairly well liberalized and the cooperatives, private firms and informal dealers competed equally for service delivery and milk marketing, building diversified collaborations with development organizations. The coffee sector is thus organized along a long vertical supply chain, while the dairy supply chain is shorter and more diversified and complex. Third, the two sectors also differ in how actors interact around innovation: in the coffee SSI, actors are relatively few and focus on supporting production technologies for coffee plantations. In the dairy SSI, many actors interact for different kinds of innovations throughout the supply chain, at the production, collection, marketing and distribution stages.

Innovating for adaptation to climate change in the coffee and dairy sectors depends on the structure and evolution of each SSI, i.e. the evolving institutional, knowledge and collaborative environment that can improve a set of innovations, including new varieties and breeds, good agronomic practices, better access to information, input and services, and efficient marketing systems. The coffee sector illustrates that this combination of innovations was lacking, which correlates well with observed difficulties in adapting to climate change. In contrast, the dairy sector shows that this combination of changes was addressed: institutional development, such as creating active and powerful cooperatives, was coupled with technological innovations such as new breeds or milk cooling machines, and better access to input, service and information. We argue that the evolution of the dairy SSI explains why the dairy sector was more resilient to climate change, something confirmed by other studies (Schreiber, 2002). For example, cooperative institutions are known catalysts for decreasing production and marketing costs, developing new markets and for better access to technical advice. The performance and efficiency of the sector, however, depends on how actors in these cooperatives are involved in interactions and the co-production of knowledge with multiple actors, private business, community organizations, and public agencies.

Economic and climate pressures are already major issues in most of sub-Saharan Africa. Policy actors have to look for micro studies on how using an SSI perspective could help farmers adapt to climate change. The impacts of climate change differ depending on the sector, the farming system, and the location. We show that sectors also differ markedly in terms of their SSI, and thus their capacity to adapt to climate change. In traditional subsistence agriculture, farms that own both crops and livestock are more resilient to climate change than specialized farms (Seo, 2010). But specialized farms could provide higher profitability and income, as well as resilience, under the condition of an adapted SSI that is able to offer efficient collaborative solutions for adaptation to climate change. The SSI perspective underlines the need for coordination or "alignment" (Geels, 2010) of both technological and institutional innovation processes. With respect to the coffee and dairy sectors in Central Kenya, we suggest that the dairy SSI could be an example for other agricultural sectors, in order to enable farmers to be climate-resilient. It may at least motivate the actors of the coffee sector to build a new SSI in which public and private actors would work together and invest in climate change adaptation strategies.

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