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Reducing food loss and waste in the Near East and North Africa

Producers intermediaries and consumers as key decision-makers

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Producers, intermediaries and consumers as key decision-makers

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Foreword

Food losses and waste (FLW) in the Near East and North Africa (NENA) are persistently high and point to the inefficiencies, unsustainability and inequalities characterizing most agrifood systems in the region. The region needs a transformation of its agrifood systems to deliver healthier diets, strengthen food security in every dimension–availability, access, stability and utilization – and meet the Sustainable Development Goals (SDGs).

FLW reduction is an important component in the transformation of the Region's agrifood systems. Addressing the drivers of FLW along value chains provides an opportunity to tackle some of the inherent problems within the NENA Region agrifood systems and to contribute to goals such as: boosting incomes and employment, improving access to nutritious food, reducing the climate footprint, and improving the use of scarce natural resources, particularly arable land and water.

There has been a remarkable evolution in our knowledge, awareness and advocacy around FLW reduction, globally and in the NENA region. The 2011 FAO landmark report ***Global Food Losses and Food Waste – Extent, Causes and Prevention*** placed FLW reduction high on the global agenda for reducing hunger and promoting the transformation of agrifood systems. The world enshrined FLW in the SDGs by setting the Target 12.3 to reduce FLW by 50 percent by 2030. The FAO 2019 *State of Food and Agriculture (SOFA)* report introduced the Food Loss Index and a new global estimate of 14 percent of food lost from harvest to retail (not including retail). In the NENA region, this figure is about 11 percent.

The present study looks at FLW from an economic perspective, considering producers, intermediaries, and consumers as key decision-makers. It builds on our accumulated experience in the analysis of the causes of FLW and solutions. It also examines more closely the incentives and behaviours driving value chain actors' decisions towards the reduction of FLW, and how loss-reduction decisions play out across the value chain. It provides recommendations to governments, international organizations, and resource partners wishing to strengthen the effectiveness of their support to value chain actors. It does so by centering the analysis on the economic incentives of these actors and the interconnectedness of decisions within value chains and, by extension, the entire agrifood system

The study comes on the heels of a global pandemic and an unprecedented economic downturn. The COVID-19 crisis has revealed the fragility of agrifood systems in the NENA region. Governments have kept value chains functioning since the start of the pandemic, but as the crisis moves into response and recovery, they wish to build back more productive, resilient and sustainable agrifood systems with less FLW. Now more than ever is the time to accelerate action towards FLW reduction as part of the broader agrifood systems transformation agenda of the region.

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Executive summary

FAO, through various initiatives, has sought to promote small-scale agriculture as an avenue to reduce rural poverty in the Near East and North Africa (NENA) region and elsewhere. Sustainable productivity improvements are considered key in promoting the quality and value of small-scale production and in supporting farms and rural economies generally. A central challenge has been to address food loss and waste (FLW) in the context of how it affects the competitiveness of small-scale farmers and the agrifood system more broadly. Reducing FLW could increase the productivity of agrifood systems in the region, leading to a more efficient use of scarce natural resources, particularly of land and water. Evidence from previous research shows that some food value chains in the NENA region, especially fruit and vegetable value chains, are characterized by notably high levels of loss, in some cases close to 50 percent of production. Nevertheless, investing scarce public resources to remedy high levels of FLW without due consideration to the underlying causes and the factors affecting value chain actors' calculated decisions may result in limited FLW reduction and an inefficient use of public funds. This fundamental analysis of causes and potentially effective solutions to FLW is the motivation of this study.

This report lays out an approach to answering basic questions regarding the economic dimension of FLW. Chapter 1 presents a conceptual model of how FLW can be analysed in the context of individual decision-makers taking actions in response to incentives, available technologies, and their economic environment. The basic argument is that food loss rates alone are not enough to signal an economic problem, although high loss rates clearly represent a misuse of increasingly scarce resources. One important theme derived from the perspective of taking producers, intermediaries, and consumers as key decision-makers in determining FLW is that the terminology 'food loss' tends to communicate the idea of a social loss that could be remedied without net costs. However, one could differentiate between losses that reduce social welfare, and losses that actors within the food chain tend to consider a 'cost of doing business'.[1] This conclusion could lead analysts to consider a more economically meaningful definition of 'food loss', which may better situate the debate around loss-reducing actions and public policies that truly create incentives for food value chain actors to minimize losses, whilst optimizing the use of scarce resources.

The measurement of physical losses can be used as an indicator, or a monitoring and benchmarking tool, to signal possible inefficiencies at different stages of the agrifood system. In addition, monitoring losses along the value chain can serve as an indicator for the overall health of agrifood systems, beyond measuring productivity at field level. Nevertheless, to accurately identify inefficiencies, the analysis should look deeper and understand the incentives and constraints that determine these physical losses. This means that the analyst should understand the incentives to reduce losses in terms of the value of marketable goods, and all the costs involved in loss reduction, before designing loss reduction actions and policies.

Refining the ability to analyse FLW and make sensible, realistic policy recommendations will require attention to the collection of information beyond physical losses. In particular, the costs

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[1] Note that what may be optimum from the perspective of individual private actors may still represent high costs to society on the aggregate (e.g. harm to the environment, increase in food prices, etc.). Thus the importance to understand the mechanisms through which private actors may be incentivized to reduce losses.

and benefits of abating losses at harvest, in the activities of intermediaries, and at the level of the consumer. In the same way, the analyst should account for and consider the changing value of agrifood commodities as they move along the marketing chain, and the evolving net benefits of food loss reduction. One should also consider the role of the organization of markets, and possible interventions and market distortions as factors determining the incentives that lead to FLW.

In addition, analysts should recognize how the process of economic development will induce predictable changes in food loss incentives. Losses at the farm level could increase or decrease with changes to markets and prices of both inputs and outputs in line with a country's economic growth, but FLW at all intermediate stages until reaching the consumer (transport, storage, processing, retail, etc.) is likely to decrease with development. The process of development and structural transformation is characterized by the specialization of labour and the separation of purely primary production activities from processing, transport, storage, preparation and marketing, which are activities that tend to be done on-farm or in local households in less developed countries. Consider the case of grains storage, for example. Farmers in poorer countries invest in on-farm storage infrastructure and techniques, often with relatively simple technologies, diverting effort and resources from productivity-enhancing activities like land preparation, irrigation, and fencing. Development that brings about sufficient agricultural surplus frees labour from production and makes it available for other activities; in the case of grains, this means specialization and improvements in pooled storage capacity and services.

Specialization reduces costs and allows increases in scale, both of which one expects to increase productivity in general, most likely reducing losses in the chain between farm and consumer. The sort of productivity gains described above in grain storage will likely occur in all such steps of that particular value chain. As countries develop, one should begin to see specialization at other nodes of the agrifood system, such as in transport, processing and retail. In the case of transport, for example, with greater specialization, decision-makers will invest in specialized equipment, such as refrigerated trucks or stainless steel tankers for milk.

There are also complementarities from productivity improvements along the value chain. For example, faster transportation to storage centres would deliver a fresher product to the warehouse, improving longevity of storage; better storage, such as the use of controlled atmospheres, will assure better quality for the processor; and improved processing will improve storage and shelf life of food delivered. Thus, development typically generates compounding effects on the efficiency of resources within the value chain. Improvements in productivity upstream will likely lead to an increase in productivity in downstream activities. There may be bottlenecks, however, if some stages of the value chain are changing faster than the capacity of the system to efficiently coordinate the movement of food. However, where there are bottlenecks, there exist potential opportunities for entrepreneurs to enter and, whilst pursuing their own profits, resolve problems associated with existing inefficiencies.

Productivity gains associated with food loss reductions are apparent beyond primary production, but with development comes an increased opportunity cost of farmers' time and increased labour costs, both of which can have an ambiguous impact on losses at the farm level. Labour-intensive crops may see an increase in field losses with development, while capital-intensive agriculture may see the opposite. A classic example is mechanization in the harvesting of horticultural products, which occurs when field labour costs increase relative to the investment costs of specialized machinery. Mechanization inevitably brings higher harvesting losses which are partially mitigated by the use of produce varieties better suited for mechanical harvesting (e.g. tomatoes). Conversely, with improvements in mechanized harvesting technology, harvests can occur in a shorter time window, mitigating weather-related losses during harvest time.

Chapter 2 provides a more formal and mathematical analysis of the same question, showing that rates of FLW, measurable at specific stages of the marketing chain such as transportation or processing, are ultimately determined simultaneously all along the value chain. Production, transportation, processing and other decisions, including those made in consumer households, influence loss and waste levels, and these decisions are influenced by incentives. These incentives take the form of prices, which shift and interact along the supply chain in response to the way people value their resources, which includes, perhaps most importantly, human time. This system-wide determination of FLW implies that interventions at one node of the agrifood system could have unexpected impacts on other nodes upstream or downstream of the intervention. Policymakers should be aware of the implicit trade-offs, and the potential for both winners and losers, when dealing with FLW abatement.

The insights and implications of efforts to model real world markets can help guide empirical and econometric work, as well as policymaking. Chapter 2 highlights the key parameters that policy analysts should track in order to understand how price and productivity changes translate into optimal loss decisions at different nodes in food value chains. In particular, the analysis shows that the response of the marginal cost of loss abatement to changes in scale is a key technological factor that determines optimal FLW decisions. This does not mean that a certain level of loss is optimum or desirable from the perspective of natural resource use for example, but rather that certain levels of loss are optimum to private value chain actors and thus the incentives to reduce losses may not be strong enough. Seen in terms of production decisions, the response of relative losses to changes in scale is a key determinant of the response of farmers to changes in incentives (i.e. farm gate prices). The consumer, particularly in value chains where intermediaries perform in competitive markets, often plays an important role in determining the effects of productivity changes at the level of producers and intermediaries on total relative and absolute losses. The responses of consumer waste to prices and income are key indicators of the impact of productivity changes on food losses generated along the food marketing chain. Although this type of analytical modeling effort does not provide definitive answers to specific policy questions, which would require a case-by-case approach, it does point to the relationships and parameters to be observed in order to make reasonably informed predictions.

The analytical approach in Chapter 2 provides some important guidance for policymaking. Reducing losses at a particular node of the food value chain in practice is equivalent to increasing productivity at that same node. This understanding links the FLW analysis to a more developed and studied literature which has examined how productivity changes disseminate across actors in the value chain (e.g. Alston, 2018). It also highlights that in order to obtain desired outcomes, policymakers should understand the nature of food value chains. For example, the model shows that reducing losses at the intermediary stage would, under normal conditions, likely increase food waste downstream at the consumer stage, whilst increasing farm level harvest and post-harvest losses. The model also provides insights on reducing household waste, given incentives, and the role of income and food prices in household food waste reduction.

Chapter 3 presents empirical applications of FLW analysis in the cases of Tunisian wheat and dairy production, and Egyptian tomatoes from harvest to wholesale, applying lessons from the previous chapters. In particular, the analysis is interested not only in measuring the loss abatement potential of some possible actions or interventions, but in measuring the profitability of such actions among different farm types (especially among small-scale farms). This would allow the identification of possible barriers to the adoption of some loss-abatement technology or management strategy, or, alternatively, whether the net benefit of adoption is simply not sufficient to support the FLW abatement measure.

The results of the analyses, estimating the determinants of losses at the farm level and disentangling the marginal economic benefits of different loss-abating actions, support the hypothesis that observed food loss is consistent with value chain actors' profit-enhancing decisions. This chapter demonstrates the value of centering the FLW measurement problem in the context of value chain actors' decisions. Choices that eventually lead to observed food loss are linked to the additional costs and benefits of loss abatement, and so loss levels are unlikely to deviate significantly from economic efficiency from the point of view of the decision maker. The empirical analysis of these specific case studies show that the benefits of adopting loss-reducing activities or technologies are not significantly higher than their costs. From a policy standpoint anything that could either make loss-reduction activities less costly, or the price of products obtained by the decision maker higher, will likely lead to lower losses. The implication for future FLW studies is that careful measurement of physical losses should be accompanied with a recording of relevant incentives, prices of outputs and costs of loss-reducing alternatives.

In addition, the analysis on Egyptian tomatoes reveals an important caveat about the comparison of the loss-abatement potential of different technologies. The evidence demonstrates that the introduction of a loss-reducing technology (plastic crates) concurrent with a traditional method (palm crates) alerted users about the source of losses, which in turn influenced the way that users managed both technologies, thus biasing the estimates of the loss-reducing impact of the new technology. Wholesalers apparently adjusted their behaviour to take advantage of the new technology, while maintaining the old. With the introduction of plastic crates, farmers selected higher-quality fruits (more likely to survive and earn a higher price at final sale). Researchers should take care to control for this confounding effect in future empirical studies.

In the case of Tunisia, both cereals and dairy are generally understood as having important economies of scale in primary production. This means that both industries face large fixed costs, which causes average cost to decline with farm size. In other words, larger farms have an economic advantage which usually leads to farm size consolidation over time. This general tendency toward consolidation has yet to be reflected in average farm sizes in Tunisia, as cereal farms tend only to have an area of 6.5 ha on average, and dairy farms only have on average 4 cows. With respect to overall costs, the data for these studies do not contain the type of information required to test for economies of scale, but they can support an analysis of the relationship between farm size and losses, and the evidence shows that the percentage losses of wheat and milk go down as farm size goes up. Although this is an additional economic force that promotes farm consolidation, it is also an indicator of the response of farm losses to price changes. The response of losses to scale among Tunisian farms indicates that farmers will reduce losses by increasing output prices. This result highlights the importance of having adequate pricing policies as part of an overall policy environment to promote an efficient (low-loss) productive sector.

Farm consolidation may not happen rapidly in Tunisia, either because economies of scale are more contained in these sectors, or because existing, low-productivity small farmers do not have sufficiently attractive alternatives to exit agriculture. Hence, although larger scale in many cases may be the solution for higher productivity and lower losses in these industries over the long run, in the short run policymakers should pay attention to the lower productivity and higher losses of smaller farms, particularly given their high prevalence in Tunisia. This study provides some suggestions based on the results presented, where it highlights the potential for promoting collective action in various forms. Nevertheless, a complete welfare analysis of small farmers should examine not only losses but productivity more generally. For example, in the case of wheat farms, the results show that the benefits to improving the use of mechanical harvesters are statistically significant even for small farms. This does not mean, however, that loss reduction would necessarily be the best way to help small and low-income farmers. For example, if better seeds or an improved fertilization schedule has a larger increase in yields than comparable reduction in harvesting losses, at a comparable cost, then the best policy, at least from the perspective of the farmer the decision maker, would be the former. This is why, to understand in depth the impact of losses on farmers' welfare, the analysis should be carried out as part of a larger effort of accounting for farm productivity. Finally, it is recommended that future studies on loss do not focus only on overall farm productivity. It is recommended that they use independently monitored loss measurements, as errors in perception may limit the ability to analyse losses, particularly when farmer-estimated loss rates are low.

Chapter 4 reviews the policy implications of the study. The underlying idea is that governments and policy analysts seeking to assess and respond to the social and economic costs of FLW should do so in terms of resources lost at different stages of food value chains. There is no simple formula to aggregate FLW meaningfully for policy purposes, because agrifood systems are highly complex, comprising the production, transportation, and transformation of products as materials move from farmers' fields to consumers' tables. Moreover, there has been little attention given in the literature to modelling and understanding the relationships between prices, production, and loss-abatement activities at particular stages of the agrifood system and their impacts on other value chain stages. The analytical approach in this report allows several policy-relevant conclusions, namely:

First, international agencies and government policy analysts should carefully consider the perspective of economic efficiency when making recommendations regarding actions intended to reduce FLW. Analysts should model and understand the relationships between loss and waste abatement decisions and incentives in a way that they can be linked with loss-reducing impact indicators. The analysis that follows arrives at the important conclusion that prices communicate across the value chain and affect productivity decisions (including rates of FLW) at different nodes of the agrifood system, and transmit upstream and downstream within the value chain leading to overall FLW.

Second, a process of policy planning and evaluation should benefit from rigorous benefit-cost analyses that create a better understanding of how actors (people) along the food value chain make decisions that lead to FLW, considering the environment in which they operate, including policies and institutions. One major conclusion that derives from this is that different actors with different attributes react differently to specific incentives. Therefore, a blanket approach to calculating food losses based only on physical quantities will likely fail to identify the mechanisms driving FLW.

Third, regarding data and statistical analysis, whilst the measurement of aggregate food loss may be useful in tracking the progress of quantity-focused targets, they are not sufficient to inform good policy design and evaluation. Policy analysts require loss information by specific value chain function to properly prioritize critical points of loss and inform the design of possible interventions. In addition, loss measurement and valuation must take place in the context of a comprehensive productivity analysis. Farmers balance food loss reductions against the benefits of other productive activities, such as dedicating more time and resources to harvesting, improving seed quality, or fertilization; and households balance food waste reduction against the benefits of other welfare-improvements. In short, actors may resist adopting technologies with great loss-reducing potential if the net benefits do not outweigh their costs, considering all resources at hand, not only food. Besides FLW quantity data, the design of effective FLW-abating policies also requires data on prices, input use, and costs.

Fourth, there is a role for monitoring physical loss quantities, especially to answer questions related to policymaking and evaluation that might be addressed by comparative studies and benchmarking. For example, are there differential regulatory frameworks that lead to possible differences in investments to abate FLW? Does market organization/structure affect FLW? Do more atomized or competitive markets have higher or lower rates of food loss? Benchmarking FLW rates within a country or industry is also valuable, giving governments a role in information dissemination. Although one would expect actors in the same industry to face the same regulatory system and technology, there are likely interesting differences in FLW rates depending on geography, firm size and perhaps other attributes. If the rate of FLW for some firms or group of firms is large compared to the benchmark, then further cost-benefit analysis would be required to assess if such a quantity is also significant in economic terms. If so, it would invite more analysis about the mechanisms/ determinants to these differences in FLW.

Fifth, FLW quantity monitoring could serve as a type of early warning system for decision-makers about the need for re-evaluating priorities related to enhancing the productivity of agrifood systems. Perhaps too much emphasis is placed on, and too many taxpayer funds go into, increasing farm-level yields, and not enough on other nodes of the agrifood system. In the broader scheme of agrifood systems transformation, policy regimes might also have to evolve in order to avoid increased FLW rates that might result from biases of outdated policies and regulations. Furthermore, information from the monitoring of FLW can be used to facilitate firm-level decision making. Firm-specific food loss information may be considered a public good and be used to inform consumers concerned with FLW about the producers/intermediaries that are more FLW-efficient. A good example of that would be creating niche markets for ‘ugly’ food.

Finally, this report emphasizes that total FLW is determined by the agrifood system operating as a whole. In any policy design focused on reducing FLW for whatever reason, decision-makers should recognize that attempting to reduce FLW at one stage of the value chain may affect other actors, perhaps negatively, at other stages. Thus the net impact of a specific FLW reduction intervention over the whole system is not obvious, and may even have an overall negative impact on the whole value chain. Hence the importance of using a system-wide approach for understanding impacts along agrifood value chains.

Introduction

FAO, through its Regional Initiative on Small Scale Family Farming (RI-SSFF) in the NENA, seeks to promote small-scale agriculture as a way to reduce rural poverty in the region. The initiative addresses challenges to the development of small-scale agriculture and advances policy options to improve productivity in a sustainable manner. It seeks to promote the quality and value of small-scale production, and to support and encourage investments to develop the farm and rural sector more generally. One key challenge of the RI-SSFF initiative relates to FLW. FLW affects the competitiveness not only of small-scale farmers but of the agrifood system more broadly. A reduction in the degree of FLW could contribute to increases in productivity of the region's agrifood systems and make more efficient use of its scarce natural resources, particularly water and land.

The RI-SSFF is currently focusing on raising awareness for decision-making and behavioural changes along food value chains, building an improved knowledge base about the issue, and implementing key food loss reduction activities. As part of these efforts, the RI-SSFF – in collaboration with the project on FLW Reduction and Value Chain Development for Food Security in Egypt and Tunisia (GCP/RNE/004/ITA) funded by the Italian Agency for Development Cooperation – conducted a study to further refine the conceptualization of FLW in the context of economic analyses and to improve the assessment framework of its impacts on economic, environmental and social indicators. The RI-SSFF and the GCP/RNE/004/ITA project generated the present report which makes use of information from field studies conducted by FAO (Table I.1), other sources, and new data and information generated within the context of this study.

Various studies on FLW conducted by FAO in the NENA region between 2016–2018 have focused on the measurement of food loss (Table I.1), following the Organization's recommended methodology to assess FLW in countries with small-scale farm and fishery subsectors (FAO, 2016a). The FAO methodology applies the '4-S' approach for food loss assessment: screening, sampling and survey, and synthesis, concluding with the production of a final report. Further guidance on 'Direct Weighing' comes from the FLW quantification methods in the Food Loss + Waste Protocol.[1] The sources of data for these studies are primary (self-reported by market participants along the food value chain and/or direct measures by researchers) or secondary. The results of these studies are estimates of the physical losses of food reported as a mass or percentage, an assessment of the main causes of loss, and solutions for different stages of food value chains (from producers, to buyers/traders, to processors and retailers). Based on this quantitative information the methodology suggests an approach to estimating the economic and social implications of loss reductions.

There are, however, two ways to build on this approach to address more completely the economic and social dimensions of FLW. First is to use the prices and costs of the products and inputs at different nodes in the value chain to form an economic valuation of the losses in terms of opportunity costs of other resources that might be used to reduce such losses. Second is to employ statistical analysis to analyse any causal relationship between abatement actions and observed losses. Typically, the problems and solutions are identified by the very economic actors themselves whose decisions result in the likelihood of losses; therefore, the proposed solutions might be effective, or they might not have a real impact on observed losses, or they might be successful in reducing losses but never be adopted due to costs exceeding their expected benefits.

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[1] The FLW Protocol is a multi-stakeholder partnership — where FAO is a member of the steering committee — which has developed the global FLW Accounting and Reporting Standard — also known simply as the FLW Standard (**http://flwprotocol.org/**)

The evidence summarized in Table I.2 (and in the Appendix to Introduction) shows that some food value chains in the NENA region are characterized by high loss levels, particularly in the case of fruits. Nevertheless, based on high loss rates only, is it certain that there is an immediate problem requiring policymakers' attention and the diversion of public resources to remedy it? This fundamental question is the motivation of this study. The first two chapters lay out an approach to answering this question. Chapter 1 delivers a broad, intuitive answer to this question by providing a conceptual model of how one can think of FLW in the context of individual decision-makers taking actions in response to incentives, available technologies and their economic environment more generally. High loss rates are objectionable, and policymakers and society should make every possible effort to minimize them across the entire agrifood system. However, the basic argument of this study is that food loss rates alone are not enough to signal an economic problem to value chain actors, so policy actions based on loss quantities and a narrow understanding of the incentives linked to food loss levels will most likely fail to achieve the expected results.

Chapter 2 provides a more formal and mathematical analysis of the same question, showing that rates of FLW, measurable at specific stages of the marketing chain, such as transportation or processing, are ultimately determined simultaneously across the value chain. Decisions about production, transportation, processing and other activities, including those within consumer households, influence loss and waste levels, and these decisions respond to incentives in the form of prices, which shift and interact along the value chain in response to the way people value their resources, including human time. This system-wide determination of FLW implies that interventions at one node of the agrifood system could have unexpected impacts at other nodes up or downstream of where the intervention takes place. Policymakers should be aware of the implicit trade-offs when dealing with FLW abatement, and the potential for both winners and losers.

Chapter 3 presents empirical applications of FLW analysis in selected food value chains in Tunisia and Egypt, applying lessons from the previous chapters. In particular, the analysis is interested not only in measuring the loss abatement potential of some possible actions or interventions, but in measuring the profitability of such actions among different farm types (especially among small farms). This would allow the identification of possible barriers to the adoption of some loss-abatement technology or management strategy, or perhaps alternatively whether the net benefit of adoption is simply not sufficient to support the FLW abatement measure. In the final chapter, the authors provide a summary of the policy implications stemming from the lessons learned.

Table I.1 FLW studies conducted by FAO in the NENA region, 2016–2018

Country (study completion date)	Study name	Study type (food loss, waste, both) / information used (primary, secondary, both)	Funded by	Source
Egypt (2018)	Food loss analysis for grapes value chain in Egypt	Loss / both	Italian Agency for Development Cooperation	FAO (2021a)
Egypt (2018)	Food loss analysis for tomato value chain in Egypt	Loss / both	Italian Agency for Development Cooperation	FAO (2021a)
Palestine (2018)	Food Loss Assessment: Causes and Solutions in the Avocado Value Chain in Palestine	Loss / both	FAO	FAO and MAS (2020a)
Palestine (2018)	Causes of and solutions to food losses in tomato and sweet pepper production in West Bank (Palestine)	Loss / both	FAO	FAO and MAS (2020b)
Egypt (2017)	Guide to prevent wheat losses from harvest to consumption	Loss / secondary	FAO	FAO (2017)
Lebanon (2017)	Guide: Preventing post-harvest losses in the apple supply chain in Lebanon	Loss / secondary	FAO	FAO (2018a)
Lebanon (2017)	Case study report on food losses in apple value chain in Lebanon	Loss / both	FAO	Chahhal, H., Chahine, H., & Tohme, S. (2017)
Morocco (2017)	Synthesis report on postharvest loss reduction for agriculture products in Morocco	Loss / both	FAO	FAO (2016b)
Tunisia (2017)	Case study of the dairy value chain in Tunisia	Loss / secondary	Italian Agency for Development Cooperation	FAO (2021c)
Tunisia (2017)	Case study of the wheat value chain in Tunisia	Loss / secondary	Italian Agency for Development Cooperation	FAO (2020a)
Tunisia (2017)	Food Waste in Tunisia : Status and strategic directions for reduction	Waste / both	Italian Agency for Development Cooperation	FAO (2020c)
Iran (Islamic Republic of) (2016)	Meat value chain losses in Iran (Islamic Republic of)	Loss / secondary	FAO	FAO (2018b)
Jordan (2016)	Vegetable value chain losses in Jordan	Loss / secondary	FAO	FAO (2018b)

Table I.2 Summary of estimated FLW in selected countries and value chains in the NENA region, 2016–2018

Country	Product	Region (year)	Critical Loss Point[2]	Food Losses	Source
Egypt	Grapes	Nubaria (2016–2017)	Farm	10	FAO (2018a)
			Wholesale	16	
			Retail	19	
	Tomato	Sharkia and Nubaria (2016–2017)	Farm	35	FAO (2018b)
			Wholesale	40	
			Retail	29	
Lebanon	Apple	Mount Lebanon, Akkar, and West Bekaa	Farm	2–10	Chahhal, Chahine and Tohme (2017)
			Cold storage	2.2–4	
			Wholesale	4	
Morocco	Soft Wheat	Saiss (2015)	Storage	14	FAO (2018b)
	Apple	Midelt (2015)	Storage	19	
			Wholesale	14	
	Citrus	Gharb (2015)	Harvest	5	
	Fig	Taounate (2015)	Processing (drying)	5–10	
	Prickly pear	Ait Baamrane, Rhamna (2015)	Harvest	16	
	Dates	Tafilalet, Draa (2015)	Harvest	14	
			Storage	19	
Palestine	Tomato	West Bank and Gaza Strip (2017–2018)	Production/ Harvest	7	FAO and MAS (2020a)
			Wholesale	8	
			Retail	4	
	Sweet Pepper	West Bank and Gaza Strip (2017–2018)	Production/ Harvest	8	
			Retail	20	
	Avocado	Qalqilya and Tulkarem, West Bank (2017–2018)	Collection Centres	21	FAO and MAS (2020a)
			Transport	9	
			Retail	16	
Tunisia	Cereal	Bizerte (2016–2017)	Farm	5	FAO (2020a)
		Siliana (2016–2017)	Farm	7	
	Milk	Bizerte (2017)	Farm	2	FAO (2021)
			Collection centre	2	
		Mahdia (2017)	Farm	1	
			Collection centre	2	

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[2] The value chain stages where "food losses have the highest magnitude, the highest impact on food security, and the highest effect on the economic result of the FSC" (FAO, 2016a).

01

Conceptual framework of the economics of food loss and waste

Productivity beyond the farm gate: productivity of the agrifood system

Perhaps the most important aspect of a well-functioning national agrifood system is the efficient use of all resources, from the farmer's field to the final consumer's table. Productivity in the agrifood system is neither merely measured in terms of per-hectare farm yields, which has traditionally been the focus of productivity analyses, nor in terms of the efficiency of land or water use, nor even in terms of total factor productivity in primary agriculture. An additional, significant component of productivity is the avoidance of losses across the entire value chain. Relatively recently, policy experts and analysts of national agrifood systems have been shifting their focus from farm productivity toward key points within the entire agrifood system where there are possible gains in productivity to be had from reducing FLW. This focus on the potential improvements of food loss reduction is particularly interesting in developing countries where there is significant potential for productivity gains from improving public goods and strengthening institutions that would facilitate the role of markets in the coordination and improved efficiency of resource use.

A well-functioning agrifood system, where food losses are minimized given the state of economically feasible and available technology, would reduce the gap between what consumers are willing to pay and what farmers receive for their products. And so, farmer competitiveness could benefit immediately from gains in productivity in the value chain due to advances in technologies and management techniques that reduce food loss. Along with accompanying reductions in on-farm, harvest and post-harvest food losses, overall productivity gains in the value chain could also lead to reductions in the total demand for farm inputs, or at least to the increased productivity of inputs in terms of a greater final amount of food delivered to consumers per hectare of land and per cubic meter of water used.

Although there has been an increased awareness of the potential for productivity improvements in agrifood systems via food loss reductions, many analytical and empirical questions remain. The first major question is with respect to the potential for significant benefits to increasing efforts to avoid food losses overall. A second important question is, where exactly along the value chain might significant loss-reductions be economically justified and thus happen? The potential benefits of food loss reduction, and the related benefits of more efficient resource use, ought to be balanced against the opportunity costs of devoting additional resources to loss abatement. Therefore, it is important that policymakers and analysts identify points along value chains that might be subject either to distortions in market incentives, or to insufficient investments in public goods, or to both, which would lead to excessive food losses from a standpoint of social efficiency.

The analytical and practical hazards of measuring FLW in terms of physical quantities

There are a wide range of estimates of the quantity of food lost and wasted. Food loss is usually defined, according to the FAO, as a "decrease in the quantity and quality of food." However, loss is usually thought of as the reduction of food which occurs along the value chain, while waste is considered food that is available to consumers for direct consumption, but, for various reasons, is not consumed and becomes trash, usually destined for landfills.

The goal of measuring physical food losses as the quantity of food that is eventually not consumed by humans seems, at first, conceptually simple. When implementing a definition of food losses, however, real-world details immediately muddle this conceptualization. This conceptual challenge has been well-illustrated by the differences between food loss definitions used by various international organizations, as demonstrated by Bellemare *et al*. (2017) and included in the Appendix. Should attempts to measure food losses count what is not harvested in the fields or lost during harvest, given the harvesting practices available? What about non-edible parts of plants? Should olive pit disposal be counted as food loss, although it is generally perceived as non-edible? And more importantly, should quantities that are eventually diverted to non-food uses be attached to the food loss column? As an important example of this non-food question, consider the case of maize, that can be diverted from human nutrition into feed or ethanol production; would such diversion be considered food loss? Choices over these small, but consequential details, lead to different definitions of food losses, as shown in Table 1.1, but more importantly lead also to large differences in estimates of food losses.

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Table 1.1 Different definitions conceptually count different portions of food produced as food losses

Food Counted / Defined as Food Loss	FAO	US ERS	US EPA	European Union	Bellemare *et al*. (2017)
Produce disposed of in landfills	Y	Y	Y	Y	Y
Inedible parts	N	N	N/A	Y	N/A
Recovered for non-human uses	Y	Y	N	Y	N
Not harvested & harvest losses	Y	N	N/A	N	Y
Physical reduction (humidity loss, size shrinkage)	N	Y	N	N	N
Loss in quality	Y	N	N	N	N

Source: Authors' simplification based on definitions in Appendix 1. Y = yes, counted in loss measurement; N = no, ignored in loss measures.

If the focus should remain on physical losses, there are reasons to follow the definition of Bellemare, *et al*. (2017). In the first place, this definition remains uncertain regarding the edibility of potential food products, a mostly culturally-determined outcome; and also accounts for losses starting from harvest downstream to the consumer. At harvest, farmers make important economic decisions, regarding how much effort (of family or hired labour) to devote to harvest activities, choosing thereby the degree of losses which are acceptable to the farmer at the first link of the value chain. Sometimes farmers may rationally choose to increase physical and quality losses, for example, by transitioning from manual to mechanized harvesting. More importantly, however, the analytically-consistent definition of Bellemare *et al*. (2017), and other authors, is preferable when assessing physical losses, because it does not count food diverted to other non-human consumption as food loss. In the context of real-world markets, when potential food such as grain is diverted to animal feed, it demonstrates that there is a more socially productive use for grain in animal production than for human consumption. In this regard, this diversion of food, or food loss by some definitions, is a socially desirable outcome and should not be considered a negative from the point of view of society. It may appear to some to be morally reprehensible to divert maize to ethanol production when every spring, farmers in Southern Africa make life-defining choices about how much green maize to harvest and thus jeopardize their production and future food security, while maize in Iowa is diverted to US automobile fuel production. However, a kernel of corn in Iowa, unfortunately, is not the same as a kernel of corn in Malawi.

Even a preferred, consistent, physical-quantities indicator of food loss, however, suffers from drawbacks, because it aggregates quantities at different stages of the value chain as if they were equal or interchangeable. From the perspective of evaluating policies this could lead to a diagnostic mistake, because as food moves downstream from the farmer, additional effort, resources and inputs are contributing to its transformation and value. Quantity estimates can be complemented by translating the loss of specific food products into nutritional measures, such as calories, or into monetary values by multiplying quantity loss units by per-unit nutrient content and/or prices. But as other authors have noted, the appropriate monetary measure would depend critically on the appropriate stage of the value chain in which specific losses are taking place, and the prices applied to the quantities lost. Even more importantly, as Koester (2017) emphasizes, when dealing with different food products along the value chain, there are quality differences at different stages, if only because of transport, packaging, etc., and perhaps transformations in the physical properties of the food item itself. And across various food-item chains, complementary services and costs vary at different stages. Thus, there is an immediate aggregation problem for dissimilar economic goods, each of which has a series of costs related to the value-adding process of moving along the value chain. Regarding the use of aggregate physical quantities, Koester remarks (2017, p. 281), "Unfortunately, how much the final aggregated figure overvalues FLW due to costs is unknown, nor can the information be used for a reasonable estimate of the inefficiency of resource use or as a potential for improving sustainability."

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Understanding the stages of food loss

Most analyses of FLW distinguish between losses in four stages of food supply systems: growers, processors, retailers and consumers (see Figure 1.1, taken from Bellemare, *et al*. (2017). This section focuses on the first three groups, although it will discuss the case of food waste at the consumer level. At the first stage, farmers and growers produce the basic constituents of what will be the final product purchased by consumers. Food losses can occur in mature crops prior to harvest, during harvest and following the harvest before the product moves beyond the farm gate down the food value chain. The farmer faces various decisions with respect to the resources used in total potential production and how much food is lost on-farm. A part of total production might be diverted to non-food uses, such as energy, compost and animal feed. The literature is ambiguous with respect to the importance of FLW measurement of pre-harvest reductions in potential production. The tendency in the literature is to emphasize both quantities left unharvested (and/or damaged during harvest) and post-harvest losses (e.g. GSARS, 2018; FAO, 2011).

In the second stage, beyond the farm, food products might pass through various phases of processing, and in some cases the cost at the farm gate might represent a small fraction of the consumer's cost of the final product at the retail level. Even products which undergo little physical transformation, such as fresh tomatoes sold in the supermarket, nevertheless are subject to transport, sorting, packaging, storage, and are made conveniently available in a timely manner to final buyers. While fresh fruits and vegetables might physically appear on the consumer's table as they do in the farmer's field, they are quite different products due to the many transformations and services that take place from field to table. Previous studies recognize that quantities might be lost due to damage during handling, transportation and other processing, and some quantities may be discarded due to poor quality and the inability to sell the product downstream at a price that would justify the use of resources to maintain the product in the value chain. This would be especially true when there is a greater scarcity of transport and storage facilities. Decision-makers in the processing stage of the agrifood system recognize that to pay for the resources used in

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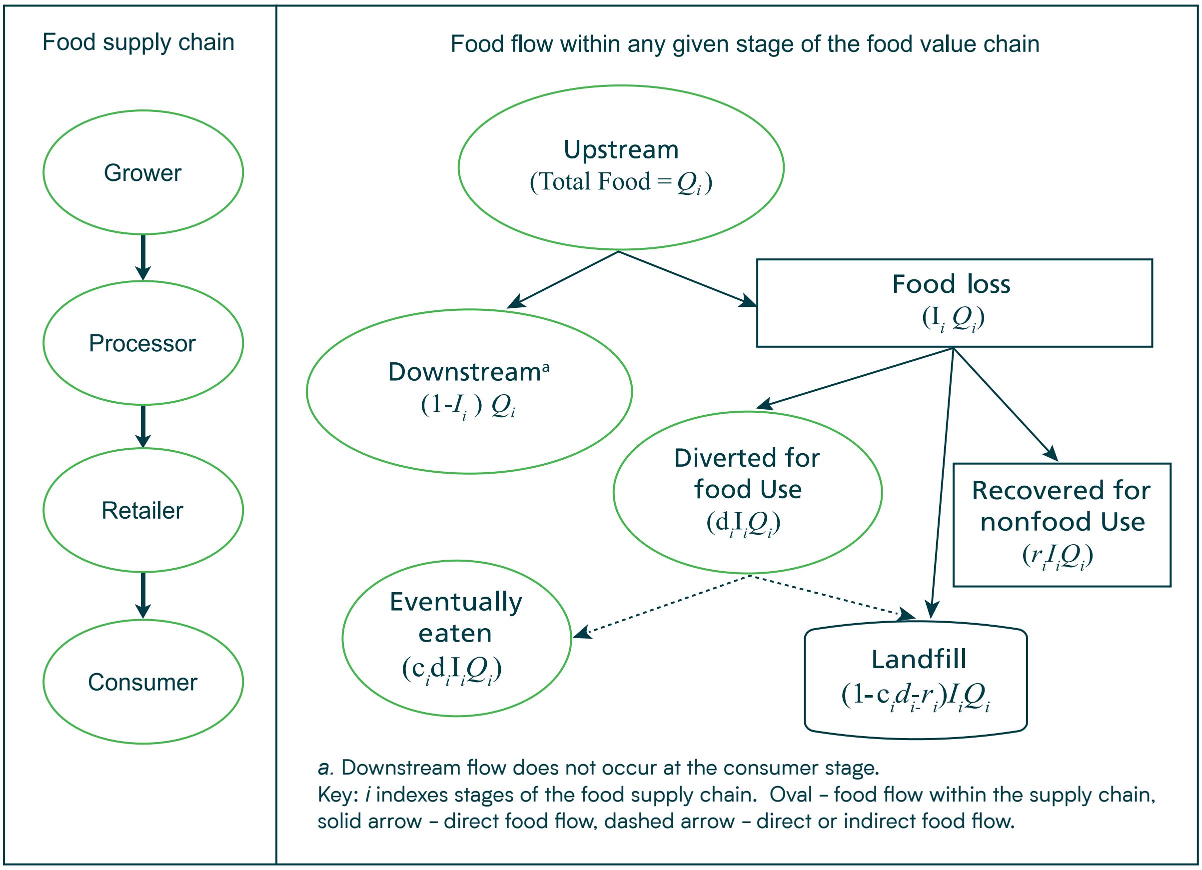
Figure 1.1 **The life cycle of a typical food item**



a. Downstream flow does not occur at the consumer stage.
Key: *i* indexes stages of the food supply chain. Oval – food flow within the supply chain, solid arrow – direct food flow, dashed arrow – direct or indirect food flow.

Source: Adapted from: Bellemare, M.F., Çakir, M., Peterson, H.H., Novak, L., & Rudi, **J.** 2017. On the Measurement of Food Waste. *American Journal of Agricultural Economics*, 99(5): 1148—1158.

moving and adding value to food, choices must be made with respect to the quality of food that eventually reaches the consumer.

The third stage on which the literature usually focusses is that of retailers, which ranges from small local shops or street vendors to open-air street markets, to supermarkets and hypermarkets. The value of the market roles of retailers is linked to the economies of scale gained from specializing as an intermediary between consumers and rest of the food chain. One role of the retailer is to serve as an aggregator of food so that final consumers have access to a large selection of food products when they wish to replenish their stock. A second important role of the retailer is to act as a negotiator and agent for consumers in accessing the highest quality goods at the lowest prices. Buyers for large retailers understand that the quality of the goods they purchase ultimately determines the prices and volumes of those goods bought by the consumer. If they buy poor quality goods and charge high prices, those goods are likely to go unsold or eventually sold at a price that would not cover the cost absorbed by the retailer. And given both competition among retailers and the scarcity of display space in retail shops and street carts, the retailer will buy the highest quality product possible from farmers, processors, and wholesalers, given the prices that they would expect to be able to charge their customers. Furthermore, in order to sustain their reputation and enjoy continued business from consumers, retailers must serve as filters of quality of characteristics that might not be immediately observable to consumers. Finally, this intermediary role of the retailer with respect to consumers and the rest of the food value chain can be applied to wholesalers with respect to retailers.

FAO has developed a food loss index that is applied at the national level for a basket of ten key commodities in order to measure the changes in percentage losses in comparison with a base period (Fabi and English, 2018; GSARS, 2018).[3] The FAO (2016a) case study methodology, on the other hand, investigates food loss magnitudes, causes and solutions at the level of specific value chains. These approaches generate meaningful information about product quantities lost and can inform productivity improvements for the agrifood system as a whole where making the best use of scarce resources is concerned. However, to do so, it is important to recognize that there are qualitative differences between products at all stages of the value chain. A tomato in the farmer's field is not the same as a tomato at the wholesaler's distribution facility, which in turn is not the same as a tomato in the supermarket's vegetable aisle. A loss of a kilogram of tomatoes at the farm cannot be equated in a meaningful economic sense with the loss of a kilogram at a supermarket, because various resources have gone into the processing of the supermarket tomato, such as the petroleum used in transport, trucker labour hours, electricity for refrigeration, the opportunity cost of using trucks to transport other products, the supermarket manager's time, etc.

To have a coherent measurement of aggregate food losses for the purposes of analysing the productivity of the agrifood system as a whole, one must be able to account for resource use up and down the value chain. Transactions prices at various stages of the value chain offer a first order approximation of the opportunity costs of the resources embodied in the product being exchanged for money. Sometimes, for more appropriate social accounting, these prices must be adjusted for possible externalities or other social costs of resources which are not borne by market participants, such as significant air pollution generated by transportation of products or greenhouse gas emissions. Appropriate values of products at the various nodes along the value chain are comparable; a USD 100 loss of tomatoes in the farmer's field during harvest, because of poor handling, is comparable to a USD 100 loss in the supermarket because of poor refrigeration, although the quantity of physical tomatoes would vary significantly. Moreover, while summing physical losses across the agrifood system would be inappropriate for productivity analysis, summing the values of losses is not. In addition, if the social cost of resources to reduce potential physical losses exceeds the value of those physical losses, then it would be inappropriate to count those physical losses as a true economic loss.

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[3] The FLI is the internationally-recognized indicator for measuring progress towards SDG 12 target 12.3, "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses".

Beyond the measurement of physical losses: understanding food losses in the context of economic choices and human welfare

Currently, national and international agencies, including FAO, are analysing food losses along various value chains in terms of physical quantities. This type of audit is important to identify potential critical points, where there might be significant net social benefits either to investments in productivity-enhancing technologies and methods, or to the correction of market distortions that result in inefficient resource use.

Finding significant food losses at certain points along the value chain would invite further analyses of the reasons for such losses, but that information alone is not evidence of inefficient behaviour or foregone welfare. One initial question that should be asked is whether food losses are associated with the absence of well-known technologies or management techniques. The absence of these technologies and methods, however, would have a potentially negative impact on welfare only if their absence were the result of poorly operating markets (so-called 'market failures') or remediable barriers to coordination (e.g. government subsidies or restrictions on competition). For example, buyers may face artificially depressed food prices (e.g. due to subsidies on production or purchase prices), and so incentives would fail to signal to decision-makers that additional resources should be shifted toward reducing food losses. Also, market concentration could block or obstruct the entry of new and more efficient competitors and entrepreneurs with technologies and management methods that would reduce food losses or channel what is potentially food loss into new products or uses. Moreover, sometimes there are information failures, such as when producers cannot credibly inform consumers that their food products derive from processes that minimize losses; and so farmers would not be able to charge the higher prices that these processes would require to be sustainable. Furthermore, large fixed costs associated with adopting loss-reducing technologies at all stages of the value chain can be a barrier to loss abatement when poorly functioning credit markets act as an obstacle to the adoption of these technologies.

In short, an important question is, where are there significant coordination failures at points along the value chain that might be mitigated by public policies and the aid of international agencies?

The following sections and chapters develop a practical but analytically rigorous approach to modelling and assessing – from an economic perspective – the potential consequences in terms of benefits and costs of reducing food losses along the value chain which is then applied to food value chains in Tunisia (wheat and milk). Wheat is a less perishable commodity, and storable under appropriate conditions, though potentially subject to international price pressures and government border protections. Milk is highly perishable in its raw state, but, because it can be transformed into a commodity in the form of powdered milk, local producers and processors often face relatively more elastic demand for their products and sometimes must respond to prices determined by international markets. These products offer the opportunity to compare and contrast the economic consequences of potential food loss reductions under different market conditions.

To analyse food losses in the context of enhancing the productivity of the entire agrifood system, the first step is to understand that losses are the results of economic decisions by a multitude of decision-makers along the value chain. When the physical product is associated with a relatively low value in comparison with other resources used in moving that product down the value chain towards the consumer, there will likely be higher physical losses, because it is more efficient to replace that physical quantity than it is to devote other resources to reducing the probability of loss. When the value of the product is high in comparison with other resources used in the value chain, then decision-makers will devote more resources to reducing the probability that the high-value product will be lost. For example, while tomatoes require human time, land and water, and other inputs, the value of a kilogram of tomatoes is relatively low in comparison with the value of a kilogram of beef, for example, the production of which requires even more labour, land and water, as well as other inputs. It is unsurprising, therefore, that decision-makers along the value chain devote more time and care and costly resources to reducing the probability of losing a kilogram of beef than they do to reducing the probability of losing a kilogram of tomatoes.

The costs incurred in reducing the probability of loss depends on the resources available, such as the state of technology and the know-how accessible to decision-makers. Without a good reason to the contrary, it is always useful in analysing economic outcomes, beginning with the idea that people are trying to do their best given the resources available to them. In the context of FLW, one should similarly begin with the assumption that people are not purposefully wasteful, but that they are behaving rationally, doing their best to balance the benefits and costs of loss abatement. In other words, at the micro-level of the individual decision maker, each person is influencing the probability of losses in a way that is best for the specific situation (that is, given the state of resources and technology).

Nevertheless, an outside observer can sometimes see an apparently large potential for food loss reduction, when comparing a specific case of significant losses to a benchmark case with fewer losses. The question then arises, why are there such notable losses? Is it possible that these large losses relative to the benchmark case are due to some easily correctable error on the part of decision-makers? Or, instead of systematic errors, are these large losses attributable to the incentives and constraints faced by decision-makers who are doing the best they can?

There is no objective method to measure physical losses and simultaneously evaluate them as a true economic loss. What would be an unacceptable percentage of loss to a large grain facility in a wealthy country would be perhaps the norm for a poor farmer in a developing country. The large grain facility has reached a level of scale and technological sophistication such that the benefits of having a relatively small loss percentage outweigh the cost. The small farmer in a developing country usually would not have access to the same technologies and low per-unit costs associated with large scale operations. Yet, both the large facility and the small farmer are comparable in that they balance their net benefits with their net costs. Any physical losses should be compared to what would have to be sacrificed in order to reduce those losses. The small farmer in the developing country likely faces a much different set of incentives and constraints, such that if he or she were to receive some windfall gift of cash available for investment, there is no guarantee that the farmer would invest additional capital in loss reduction technology rather than investing in other household improving assets, such as a clean water supply.

Nevertheless, taking the agrifood systems in developed countries as benchmarks would be useful in identifying potential bottlenecks and coordination problems in developing countries. Unfortunately, economic losses are often more difficult to identify compared to physical losses. When high physical food losses are observed along the value chain in comparison with developed country benchmarks, it might signal some bottlenecks or distortions to economic incentives that block the adoption of loss-reducing technologies or management methods. Policymakers might then address these bottlenecks or distortions. For example, in the analysis of comparably low levels of productivity in agricultural systems in developing countries, a significant bottleneck is often the result of a lack of well-functioning credit systems which restrict the adoption of new methods requiring high, upfront fixed costs. Poorly functioning credit markets affect the adoption of all types of productivity-enhancing technologies, including those that lead to reduced food losses.

As Hodges ***et al***. (2011) note, in contrast to developed countries, "the issue [in less developed countries] is inefficient postharvest agricultural systems that lead to a loss of food that people would otherwise eat, sell or barter to improve their livelihoods." However, inefficiency, as defined by these authors, is described in the engineering/physical-quantity sense, and is assessed using developed countries as a reference. The question for policymakers in a developing country should be: what are the levels of physical food losses that are economically feasible in the context of the country's level of development and the capabilities of the real human actors that are operating within the country's existing agrifood system?

Reducing or eliminating food losses per se should not be the point of policy aiming to improve the welfare of households dependent on the agrifood system. Nevertheless, notably large 'inefficiencies" in relation to the developed country benchmark could signal to policymakers that policy changes are recommended, although the details of effective policies would have to be appropriate to the country and not merely formulae imported from developed countries. Eliminating distortions and resolving problems of coordination would allow individual decision-makers to take steps to improve their individual welfare and make more efficient use of the resources available to them at the micro level. Improved agrifood system resource productivity would be the result of reducing distortions and coordination problems. Increased overall productivity would likely (although not guaranteed) also entail a decrease in food losses, at least in percentages terms. As will be discussed below, with an increase in agrifood system productivity and with overall economic development may come an increase in absolute levels of FLW, as well as a decrease in the percentage of losses.

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A basic conceptual model of actors in the agrifood system and their relation to FLW

This section develops a practically applicable model that is sufficiently general to accommodate the different conditions that apply in the real world to food products of typical interest when measuring FLW. This model is developed with more algebraic formality in the Appendix, and in the next chapter. The purpose of formalizing a behaviour-based model is to develop guidelines for data collection and potential policy interventions. The basic modelling effort considers four levels along the value chain, as conceptualized by Bellemare *et al*. (2017), FAO (2014), FAO (2011), Hodges *et al*. (2011), and Stenmarck *et al*. (2016), among others. The first is the primary producer, where losses can occur from harvesting, to on-farm handling, to sale at the farm gate. The second level includes intermediaries, where losses occur in transportation, storage, and processing. The third level includes the buyers/retailers, which could be larger-scale retailers (supermarkets), small local retailers, or international markets (this third level would also include the HORECA sector). The fourth level is at the household, where cross-country evidence suggests a wide range in the proportions of food wasted.

One important aspect of this model is that FLW are jointly determined along the various decision points in the agrifood system. One central characteristic of decisions by individual actors in the value chain is that these actors seek to make the best use of their resources at their individual, micro-level perspectives. That is, individual decision-makers are using resources such that the marginal benefits of additional effort and use of inputs is equal to the marginal costs. One immediate consequence of this focus on the micro-level decisions of individual actors in a market context is that productivity decisions at one node are communicated throughout the value chain via prices. Reducing losses at one node likely has impacts both downstream and upstream of the value chain. Of course, each market situation would have its own context and particular attributes, and exactly how productivity decisions are communicated to other actors in the agrifood system is contingent on the organizational structure of various markets, depending on the degree to which some actors have market power, such as in the case of a monopsony or monopoly.

At the level of the farmer, various characteristics are important in determining the benefits and costs of food loss reduction, such as scale, technology and input costs. The key conceptual idea to keep in mind is that farmers and growers face different opportunity costs that drive harvest and post-harvest decisions regarding resource use, which eventually results in the probability of losses. Usually, although not always, higher levels of overall productivity are associated with larger scales of operation, and likely post-harvest food losses at the farm level are, at least in percentage terms, greater than those in small farms. Nevertheless, regardless of scale, farmers should be utilizing resources to maximize the net benefits of loss reductions.

An important consequence for data collection is that analysts should have information regarding food losses and the scale of operations for different crops and different production systems. The marginal cost of reducing both harvest and post-harvest food losses at the farm level are likely different across product type, distance to markets, climates, labour availability and cost, and other inputs. Simply counting the number of units lost for any specific product will not yield the relevant information necessary to assess the costs and final welfare effects of reducing these losses. For example, if decisions regarding food loss reduction are sensitive to labour wages (e.g.

the importance of labour time in careful harvest and handling), an increase in the opportunity cost of farm work (because of, say, an increase in the opportunity for off-farm employment and non-farm wages) would lead to a larger percentage of food losses, although rural household welfare would improve.

Furthermore, there are almost certainly different effects of increasing scale on food losses depending on the nature of the product. Mechanization and scale are highly correlated and mechanized harvesting produces more food losses in comparison to hand harvesting. Investment to reduce food losses is made jointly with investment to increase yields per hectare and the overall scale of production. An important question for data collection is the relationship between quantity-enhancing new technologies and the cost of food loss reduction. Does an increase by, say, ten percent of a farmer's total production increase or decrease the net benefits of a reduction of food losses by more or less than ten percent? A related question, also important for data collection, is the sensitivity of quantities and percentage food losses to changes in product prices. A reduction in the price of the farmer's product signals to the farmer that he or she should devote fewer resources to all aspects of production, including to those resources devoted to food loss reduction. The final result for food losses, however, is ambiguous, because reduced output quantities could have a negative or positive impact on the marginal cost of food loss abatement. This question can only be resolved by having information on the specific production system and the cost of the resources under the farmer's control.

Another important question is the role of random events in the ultimate level of food losses at the farm level during any particular production cycle. The absolute level and percentage of food losses depend on climate, pest damage, and unanticipated changes in input costs. A farmer must make the bulk of input decisions many weeks, if not months, before production quantities and losses are realized. Farmers are making decisions based on probabilities, and they are balancing future benefits against the risks of poor if not disastrous outcomes. The production systems and crops that the farmer eventually adopts, and the routine or customary habits of input use, are the consequence of many years, if not generations, of confronting the risks associated with climate, market changes, and political shocks. Farmers are likely to have adapted their production systems such that they have made a balanced choice between accepting a higher percentage of food losses and reducing the risk of negative outcomes. Again, some effort should be made to collect information regarding the relationship between risk and food losses.

A likely underlying cause of high food losses can be found in credit market distortions and the potential role of credit or other related constraints in the adoption of loss-reducing technologies or methods at production and other levels in the agrifood system. Not only does a well-functioning credit market allow farmers to spread the fixed costs of new technology adoption over time, but it gives them confidence to withstand shocks to income that might accompany the adoption of novel but uncertain techniques that might enhance productivity, including the reduction of food losses. In analysing the potential for food loss reductions, one should take into account access to credit markets or lack thereof for different types of farmers. Credit access is likely to vary with geography, household income portfolios, and the availability of collateral (such as land). The ability to obtain credit is also sensitive to the underlying uncertainty of different production systems and the volatility of product prices, and to the scale and wealth of individual farmers.

At the intermediary stages of transport, storage, and processing, both scale and market structure are key determinants of productivity, including losses. Especially important is the role of prices and public goods in reducing or exacerbating food losses. The cost of transport, closely related to fuel costs and labour wages, determines how closely packed trucks and storage facilities are. Decision-makers in transport will balance the cost of trucking against the probability of loss. As the cost of space in transport increases, trucks will be more closely packed and rates of damage and food loss will likely be higher. As wages increase, the cost of careful handling will also increase, and decision-makers will likely accept higher food losses due to mishandling and delays in transport. Moreover, road network conditions and distance to markets are contributors to food losses. While decisions over handling and filling trucks are taken at the level of the individual farmer, trucker and transport company, decisions over the conditions of the roads are usually a matter for governments, as they are public goods.

In collecting data on food losses at intermediate stages, attention should be paid to the degree of losses that occur in different cost situations and along the value chain. For example, are food losses sensitive to the intensity of traffic flows in the system? Are higher percentage losses acceptable during periods of greater scarcity of transport and labour? Are different technologies more or less susceptible to variation in food losses due to changes in the cost of logistics? Much of the information at the immediate stages of the value chain would likely derive from expert opinion and individuals with first-hand knowledge.

In the case of processors and retailers, an interesting incentive problem is likely to occur. The cost of the basic product received by the processor or retailer is likely positively correlated with the care and attention in handling and sorting the product. As productivity levels at the farm and at the transport stage increase, and the price of the raw product declines, processor and retailers are likely to reduce their use of resources to minimize food losses, all other things been equal. Cheaper raw products mean that the processor can increase volumes purchased and be more selective of the food input reaching buyers, increasing the amount of the raw product wasted or diverted to low-value uses.

Scale of processing and retailing is likely also important, although the relationship to the percentage of food loss differs according to raw materials and final product. For example, processors of high-value goods for international markets are more apt to be selective both at the stage of product purchase and during selection; it would not be surprising if such processors experience higher food losses in comparison to those who are more willing to accept lower quality raw materials and who orient their final products to less demanding buyers.

Data and information at the level of processors should take into account the nature of the final product and the scale of processing. Greater processing and retailing scale likely permits an overall increase in productivity, all other things being equal, and this increase in productivity is likely manifested in reduced food losses overall, although perhaps in an increase in the selectivity and diversion of raw materials to non-food uses. Interestingly, processors oriented to more sophisticated consumers are likely to be more selective at the point of purchase and during the initial stage of the processing, thus contributing to higher food losses; but once the raw material enters the stage of transformation and packaging, the food product is more valuable, and processors are more likely to devote more resources to loss reduction.

Also, at the intermediate stages of the agrifood system, market structure – such as contracts (or lack thereof), monopsony, or vertically-integrated firms – can introduce complications to the analysis of FLW. Often, market structures, such as vertical integration, have arisen as a means for decision-makers to increase productivity and returns on resources used in production. In other cases, market structures are the result of government policy, either directly, as in the case of licensing and government procurement, or indirectly as in the case of an environment of poor contract enforcement or frequent political disruptions which makes large firms more resilient to shocks. While some forms of market concentration and vertical integration in the intermediate stages of the agrifood system might have grown spontaneously from competitive market forces, others may be less benign. This is an important consideration when it comes to productivity issues in the agrifood system, especially when large intermediaries might present distortions to price signals between consumers and producers. For example, large intermediaries protected from market competition might be more concerned with the total volume of food product flowing through the system from farm to table than they are with food quality and wastage.

At the retail level, again market structure is important, especially in terms of whether retailers are able to signal their requirements to other decision-makers upstream of the value chain. At the level of retailers and their relationship to households, any modelling and data collection efforts should incorporate the cost of accessing food markets, income levels, and the role of retail practice.

It is important for analysts of FLW to recognize the importance of prices to inform resource usage best practice across decision nodes in the agrifood system. The reduction of food losses at the farm and intermediate stages will likely lead to a reduction in the price of the food product downstream of the chain and at the level of the consumer. Technological improvements at early stages of the value chain, which lead to reduced food losses at those stages, will result in unambiguous welfare gains overall, but especially to consumers. However, such technological gains at early stages of the value chain, by reducing the price of food flowing downstream, may induce changes in resource use such that there could be greater food losses at later stages. Any policy aimed at reducing food losses directly at a particular stage of the agrifood system should be assessed in the light of potential consequences of changes to food loss abatement incentives at other stages, upstream and downstream of the specific node at which an intervention takes place.

Furthermore, and more worrisome for the welfare of farm households, productivity gains at downstream stages of the value chain, such as a significant reduction in food loss, could be communicated upstream to farmers in the form of downward pressure on farm-gate prices. Food loss reductions in transport, processing and retail (and also in consumer households) are effectively a new source of competition for farmers, equivalent to increased imports or any other new source of supply. Greater productivity in the agrifood system will reduce the demand for basic factors of production, such as land and water; but productivity gains downstream will also reduce the demand for farm labour, and reduce the incentive in production, including the incentive for reduction of food losses at the farm level.

Consumer food losses or waste

Upstream of the consumer along the value chain, food is either an output, or an input that is transformed or modified to be sold as a value-added product. Along these stages of the agrifood system, decision-makers will generally abide by the rule of reducing food losses until the cost of any further reduction in losses exceeds the benefit of that additional loss reduction. The end-consumer, however, has different incentives. He or she will buy and consume food, deriving utility from this consumption, constrained in two notable ways: by wealth or income that limits their consumption options, and by constraints to free time, to income generation, to time devoted to leisure (a good), and to time dedicated to the preparation and consumption of food. The difference between consumer decisions and those upstream of the value chain merit a separate discussion in the study of food waste at the household level.

The scattered evidence of measured household and consumer food waste suggests that food waste positively correlates with income. For example, in Great Britain, during the pre-war era, Cathcart and Murray (1939) estimated that only one to three percent of dietary energy intake was wasted within households; whilst another nutritional study in the mid-1970s revealed that households wasted six percent of dietary energy intake (Osner, 1982). Another more recent study suggests that food wasted in British households amounts to 25 percent of food purchased by weight (note, not energy content). In the United States of America, Kantor (1998) estimates consumer-level food losses at 20 percent of gross dietary energy intake. FAO (2011) estimates that per capita food waste at consumer levels in developed regions of North America and Europe are about 95–115 kg/year of food, whilst per-capita food waste in Sub Saharan Africa and South Asia is only 6–11 kg/year (that is, between five and ten percent of losses seen in developed countries). Stenmarck *et al*. (2016) estimates an even higher level of consumer food waste in Europe, as much as 173 kg/year per capita. Parfitt *et al*. (2010) conclude that, after reviewing the available evidence, household income correlates positively with household food waste. This is a robust result that indicates that, as countries develop and income grows, consumer food waste increases; similarly, wealthier countries have higher levels of food waste at the household level than less-developed countries; and, comparing survey data within countries, nutrition studies show that wealthier households waste proportionately more food than poorer households.

To understand this consistent result, it is important to start with one of the strongest maxims in economics, Engel's Law. Formally, this law states that as family income increases, the percentage spent on food decreases; that is, the income elasticity of demand for food is less than one. In practice, as countries grow economically, the proportion of disposable income spent on food (food budget share) declines, and the priority of food in calculating the national Consumer Price Indexes declines. In short, food budget shares are higher in poorer countries. In a cross-country study for example, Muhammad *et al*. (2011) show that in poor countries, such as the Democratic Republic of Congo, food budget shares rise above 60 percent, whilst in developed countries, food budget shares are less than ten percent of income and as low as six percent in the United States of America. Concomitant with this reduction, and explaining it, is a reduction in the real price of food, and the ratio of food prices relative to income, as the price of food remains constant or falls whilst incomes grow. This means that as countries develop, and for wealthier households, food is a relatively less scarce and relatively less valuable good/resource.

The other key feature of development and income growth is that it leads to a rise in the opportunity cost of time. As incomes rise, the cost of time spent on leisure or food preparation rises, because the alternative use of time, i.e. income generation, becomes more profitable. These two consistent features of development and income growth explain why food losses at the household level increase with income. As the opportunity cost of time increases and the real price of food falls, going to the supermarket becomes more expensive, and from the perspective of the consumer the real value of food waste falls . Therefore, an increase in food purchased but not consumed is completely rational, and it is unfortunately in the wealthier consumer's interest to waste food in the household to reduce time spent going to the market and in doing other tasks (and their related costs).[4] Furthermore, economies of scale in food processing, logistics and retail promote further losses, not only by reducing the real price of food, but also by promoting bulk purchases. For example, when a consumer faces a 'buy 2, get 3' offer at the market, the rational buyer should make this purchase even if they expect to waste a third of that purchase. This type of bulk-buying may be thought of as promoting waste, but exists because it increases profits for retailers and welfare for consumers.

Another common feature of development is the growing opportunity cost of women's time (as wages increase or the value of non-housework activities increases), which encourages higher female participation in labour markets, which in turn leads to less time for traditional household chores, among them food preparation. In poorer and more traditional societies, women spend significant amounts of time preparing food, using techniques that promote longer-term preservation (e.g. marmalades, broths, sauces, meat preparation like sausages, pickled vegetables, etc.). The implicit goal of this preparation is precisely to reduce food loss by facilitating its conservation. In wealthier societies, this has become more costly in terms of time, which in turn promotes the alternative of industrially-processed foods that result from the economies of scale and reductions in the real price of food. It is also expected that, as home food processing diminishes with development, so too do the commonly-eaten parts of plants and animals change, likely limiting what is considered edible at home.

Food waste levels at the household level can be brought down, for example, with improved packaging technologies, improved household storage, and even through campaigns that raise waste awareness. But there are powerful economic forces (in the form of opportunity cost of time) that drive increased consumer food waste as incomes grow. Once one understands the drivers of food waste in more developed countries, and how they correlate with income, one may anticipate that increased welfare and improved food security brings about increased consumer food waste in poorer regions, such as Sub-Saharan Africa. Policy still has a role in minimizing the growth of relative food waste by intensifying awareness-raising campaigns that change consumers', and probably retailers', perceptions about the impact of high food waste on future welfare. The more consumers internalize the cost of, say, environmental degradation caused by food waste on the economic prices that they pay for their food, the more incentivized they will be to reduce waste.

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[4] There is an *additional option value* of having food (particularly perishables) at home, whereby a rational consumer may wish to "overbuy" what they expect to consume so as to have the option of having fresh produce available when needed, instead of not having the produce or incurring the fixed cost of going to the market.

The effect of market structure and policy

As noted above, any FLW problem leading to any socially relevant economic costs will ultimately be the result of a combination of many individual decisions. In the aggregate, the end result for FLW will be determined by the way in which markets are organized. For example, there are some markets best characterized as atomized, with many price-takers all along the value chain. In other cases, there are protected, private or state monopolies that dominate given markets. In many markets there are significant distortions to the price system driven by government policies. How might the way markets are organized exacerbate or moderate observed FLW?

In the ideal scenario of competitive markets, prices signal to many price-taking decision-makers where resources should be invested to maximize profit. All the costs and benefits of decisions taken are internalized by producers and consumers, and so prices reflect the net marginal social costs of resource use. This would apply to decisions over the quantities produced and the resources dedicated to reducing food loss. It would also include the possibility of investing in eco-friendly production processes and in the development of lower-loss products (such as ‘ugly produce’) that might appeal to consumers interested in buying eco-friendly goods. However, there are real-world obstacles to approximating the textbook competitive market; obstacles which result in problems of coordinating resource use.

For example, monopolies and monopsonies disrupt price signals by creating a wedge between marginal social costs and marginal social benefits, and so can lead to a general reduction in productivity and larger food losses than might otherwise occur in a competitive setting. A large buyer and seller would restrict purchases from farmers compared to the competitive benchmark, pushing down farm-gate prices and diminishing incentives to devote farmer resources to loss abatement. In a competitive environment, firms would compete across several attributes: price, convenience, and other characteristics, such as a food product’s shelf-life. A source of inefficiency, in a situation of weak threats of competition from existing and potential competitors, is the slow turnover of technology, methods and managerial habits. Without competitive pressures from new entrants who would bring new products, ideas, technologies and methods, monopolies and monopsonies would have less of an incentive to offer higher-quality goods, such as produce with better packaging and/or a longer shelf-life.

A monopolist has incentives to restrict supply to consumers in order to raise prices above competitive market levels. One way of restricting that supply is by absorbing higher losses. Similarly, losses along the value chain, and shifting product to non-food uses, would be a way that a large intermediary with market power could enhance and reap the benefits of the volume of product moving through the food value chain but simultaneously restrict the quantities, and thus raise the prices, of the food finally reaching the consumer.

From a welfare perspective, in terms of the best use of resources available to communities and society, government subsidies and regulations can also have perverse effects on productivity in various stages within the agrifood system. As with large players in the value chain who take advantage of their control over prices, government interventions can drive a wedge between the marginal social benefits and marginal social costs in transactions between decision-makers. One

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clear historical example related to food waste has been to artificially suppress the price of so-called ‘wage goods’ in urban areas, which is an indirect method of countering pressures to raise wages (paid by industry and large employers) by reducing the cost of the consumption basket of urban workers (Schiff and Valdés, 1992). As a way of supporting the real incomes of the relatively poor, the prices of important food products, such as bread in Tunisia, are either kept low by controlling the cost of the raw materials moving along the agrifood system, or by directly subsidizing the cost at the retail level. Artificially suppressing prices at the consumer level encourages over-purchase and waste, which is particularly evident among some higher-income households.

Furthermore, most government regulations and subsidies that focus on the production of goods (e.g., primary farm products) or services (e.g., transport from farm to processor) have the tendency to emphasize volume over quality. This happens mainly because volumes are easier to monitor than quality. As a result, private actors, responding to government incentives, tend to shift resources from maintaining the quality demanded by consumers toward the quantities being subsidized. For example, if new technologies become available that would, say, extend the shelf-life of some subsidized food product, or increase the proportion of undamaged produce arriving at a distribution point using subsidized transport, these methods would likely not be adopted if they have an associated cost, and if subsidies are based on volume (rather than shelf-life).

Finally, one should note the effect on FLW of government trade policies and protectionism. Integration with world markets (in the form of foreign investment, export market demand and competition with imports) provides an impetus to competitive pricing and to the adoption of new technologies and standards, all of which improve productivity along the value chain. To the degree that government policy insulates the domestic agrifood system from competition abroad by restraining either exports or imports, domestic markets, especially those dominated by large intermediaries, would tend to be sluggish in adopting new technologies and methods.

When there are obvious productivity problems related to primary production and post-harvest food losses that are potentially resolvable by making profitable investments in better coordination, private actors in the agrifood system would tend to do just that. In some contexts, vertical market integration for example, either directly (via incorporating several stages of the transformation chain within one firm), or indirectly, (via contracts), has been observed as a response to the relative inefficiencies of atomized markets consisting of many small farmers, transporters, processors and other decision markers. When transaction costs, asymmetric information, freeloader problems, etc., prevent the textbook use of prices in anonymous and one-off transactions to signal in a precise way the benefits to consumers and costs to producers of product attributes, other forms of coordination become potentially attractive. Vertical integration fosters the credibility of longer-term commitments and allows for detailed communication of best practice among actors at various stages of the value chain. For example, some varieties of horticultural produce, such as tomatoes, are more prone to damage during harvest and shipping. Contractual arrangements have arisen, both to assure processors and supermarkets of receiving tomato varieties less prone to damage with longer storage times, and to assure farmers of a profitable outlet for their products.

One source of inefficient coordination in developing countries at the level of small farmers and rural entrepreneurs involved in post-harvest activities is the high fixed cost of new technology adoption accompanied by poorly-functioning credit markets. Private firms, acting as formal integrators or as suppliers and buyers with longer-term implicit contracts with farmers, often serve as coordinators of finance for small producers, either advancing their own funds or negotiating better terms with creditors. Cooperatives and farmers’ associations, by pooling resources, are other forms of organization that improve the ability of small farmers to access credit and new technologies. Farmer cooperatives serve as integrators, from coordinating large-volume input purchases, to training, to providing storage facilities, to serving as marketing agencies.

Economic development and FLW along the value chain

Losses at the farm level could increase or decrease with changes to markets and to the prices of both inputs and outputs associated with a country's economic growth, but FLW at all intermediate stages (transport, storage, processing, retail, etc.) until the consumer would likely fall with development. The process of development[5] and structural transformation is characterized by the specialization of activities and the separation of purely primary-production activities from processing, transport, storage, preparation and marketing; activities usually done on-farm or in local households in less developed countries. In the case of grains storage, for example, farmers in poorer countries invest in on-farm storage infrastructure and techniques, often with relatively simple technologies, diverting effort and resources from other activities that can increase production. The farmer is typically a small producer, so the size of home storage facilities is usually limited, and efforts and capital invested in the construction and maintenance of storage capacity would be unavailable for investment in land preparation, irrigation, fencing, and other productivity-enhancing activities. With sufficient agricultural surplus, which allows labour to be moved from production to other activities, people begin to specialize in the transport and storage of agricultural output. The advantages of pooling storage capacity and services have long been recognized.

Accompanying this economic transition are improvements in storage, with accompanying important reductions in FLW. First, when specialization in storage occurs, the scale of operation becomes substantially larger, permitting the spread of large fixed costs, such as storage space and insurance, over larger volumes and subsequently reaping the advantages of lower average costs. These scale economies are particularly important in the case of refrigeration and climate control. Furthermore, the specialization of labour increases productivity by facilitating learning-by-doing (that is, the accumulation of job-specific human capital) and by removing the inefficiencies of frequent labour-switching between activities. Together with larger scales and labour specialization comes improved, specialized technology, which regrettably small farmers tend not to be unable to access profitably. Examples of these technical advances are better and faster drying facilities, improved pest control programs, faster sorting and testing, better construction materials, etc.

Specialization reduces costs and allows increases in scale, both of which have the potential to increase productivity in general and reduce losses in the chain between farm and consumer. The sort of productivity gains described above in the storage example will likely be seen in all food-related activities between the farm-gate and the final consumer. As countries develop, one should be able to observe specialization at the other nodes of the agrifood system, such as in transport, processing and retail. Together with this specialization, as in the storage case, development should be accompanied by increased productivity in these specific activities, which likely translates into lower FLW. In the case of transport, for example, with greater specialization, decision-makers will make investments in equipment, such as refrigerated trucks or stainless-steel tankers for milk.

There are also complementarities to productivity improvements along the value chain. For example, faster transportation to storage centres would deliver a fresher product to the warehouse,

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[5] The concept of development (or economic development) implies higher levels of specialization and also changes in certain key variables that determine well-being, such as incomes (cost of labour), health, education, etc.

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improving longevity of storage; better storage, such as the use of controlled atmospheres, will assure better quality for the processor; and improved processing will improve the storage and shelf life of food delivered. Thus, with development, a compounding effect of the improvement in the efficiency of resources within the value chain should be seen. Improvements in productivity upstream likely correlate with more productive downstream activities.

There may be bottlenecks, however, if some stages of the value chain are changing faster than the capacity of the system to efficiently coordinate the movement of food. An example is the case of potentially high productivity farmers in Egypt having adopted export grape varieties and improved growing methods for high-value table grapes targeted to markets in Europe, the Kingdom of Saudi Arabia and elsewhere, but transportation systems and logistics have yet to catch up to the potential. But where there are bottlenecks, there are potential opportunities for entrepreneurs to enter and, while pursuing their own profits, resolve problems associated with existing inefficiencies.

Productivity gains are clearly associated with food loss reductions beyond primary production, or beyond the farm gate, but with development comes an increase in the opportunity cost of farmers' time and increased labour costs, which will have an ambiguous impact on losses in the field (within the farm gate). Field losses for labour-intensive crops may increase with development, while capital-intensive agriculture may see the opposite. A classic example is the mechanized harvesting of horticultural products, which occurs when field labour costs exceed the investment costs of specialized harvesting machinery. With the mechanization of harvesting comes higher harvesting losses, which can be partially mitigated by the adoption of varieties better suited for mechanical harvesting, e.g. tomatoes (Thompson and Blank, 2000). On the other hand, as technologies for mechanized harvesting improve, harvests can occur within a shorter time window, allowing for minimization of weather-related losses during harvest time.

When considering food losses within the farm, one must recognize the simultaneity of productivity-enhancing decisions. Higher productivity may be achieved by traditional means, such as by producing better varieties and increasing the efficiency of inputs; or it can be achieved by reducing losses during harvest. These choices are not mutually exclusive, and farmers employ them simultaneously to maximize their welfare, which includes the use of their time. Farmers will not only focus on loss abatement, and in fact may decide to take actions that result in increased losses depending on conditions and incentives. Such actions increase productivity by shifting resources to other uses. In other words, both the percentage of food losses and the absolute quantities of loss may increase, while farm productivity increases, which ultimately increases welfare.

Conclusions

A key takeaway from the perspective of taking producers, intermediaries, and consumers as key decision-makers in FLW is that the analyst should be careful with the use of the term 'food loss'. The word 'loss' may transmit the idea of a social loss which could be remedied without incurring net costs. However, as highlighted in this report, it is important to differentiate between losses that reduce social welfare, and losses that actors within the food chain tend to consider a 'cost of doing business'. This conclusion should lead analysts to reconsider the definition of FLW and move towards an economically meaningful definition of 'food loss', one that is more conducive to designing loss-reducing actions and enabling policies that ultimately influence actors into minimizing losses.

Measurement of physical losses, however, can provide a useful indicator, or act as a monitoring and benchmarking tool that signals potential inefficiencies at different stages of the agrifood system. In addition, the extension of loss-monitoring along the value chain can counterbalance the focus on farm productivity as the sole indicator of overall agrifood-system health in developing countries. Nevertheless, to accurately identify inefficiencies, the analysis has to dive deeper to understand the incentives and constraints that determine the observed physical losses. This means that it is important to understand loss-reduction incentives in terms of the value of marketable goods, and all the costs involved in loss reduction, before making a claim that there are effective policy remedies.

Refining the ability to analyse FLW and making sensible, realistic policy recommendations will require attention to the collection of information beyond physical losses. In particular, the analyst will need to pay attention to the costs of abating losses at harvest, in the activities of intermediaries and at the level of the consumer. In the same way, it is important to account for the changing value of agrifood commodities as they move along the value chain, and the evolving net benefits of food loss reduction. Also, one should take into consideration the role of the organization of markets and possible interventions and market distortions as factors determining the incentives that ultimately determine FLW. Finally, the analyst should recognize how the process of economic development will alter these incentives and induce predictable changes in the evolution of food loss incentives. These considerations form a conceptual foundation for the analytical approach and empirical application of FLW analysis presented in the following chapters.

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02

A system-wide market model for food losses and waste

A system-wide market model for food losses and waste

The increase in attention to the problem of FLW has brought about important advances in loss identification and measurement (Bellemare *et al*., 2017; Fabi and English, 2018; FAO, 2016a). This effort to measure FLW is no simple endeavour, because food usually moves within complex agrifood systems, and is transformed and transported in multifaceted ways as it goes from farm to table. Less attention, however, has been given to formalizing the interplay of loss abatement decisions at particular nodes of the value chain. Little is known of the role of loss abatement at one stage of the value chain in influencing decisions at other nodes; certainly, there has been little modelling of these relationships in a way that they can be linked with observable outcomes and econometric quantification. This chapter is a contribution to rigorous economic modelling, moving along the lines suggested by de Gorter (2014). It provides a modelling framework, consistent with well-established microeconomic principles, to study the effects of FLW changes at one stage of the value chain, and the impacts of FLW decisions on other actors in the agrifood system within a market framework.

Following Anriquez *et al*. (2018), one can begin with the idea that food losses result from decisions made at nodes within the food value chain, where different types of rational economic agents determine observed outcomes. The first section below presents a simplified model of the actions induced by incentives and within the constraints faced by the three basic actors most important to the determination of FLW: farmers, intermediaries, and consumers. The models of individual choice are simple but are meant to account for the relevant factors in decisions taken by the three actors, which eventually result in the total observed FLW, looking at the value chain as a whole. Individuals along the value chain are coordinated by exchange prices, first between farmers and intermediaries, and then between intermediaries and consumers. The modelling strategy sets out individual decision rules, initially of price-takers, with no government interventions and a competitive intermediary sector, and follows the consequences of these decision rules for total FLW and welfare indicators in a market equilibrium.

The decision rules of the three types of market participants are addressed in turn, and some comparative-static results regarding the link between product prices and FLW are derived. Then the three participants are linked via prices defining an agrifood-system-wide market equilibrium. The idea is to demonstrate how prices communicate all across the value chain and how productivity choices are made (including rates of FLW) at different nodes in the agrifood system. Finally, the discussion turns to how changes in productivity at particular nodes disseminate upstream and downstream within the value chain, and what the expected outcomes are in terms of overall FLW.

Comparative statics, following the implications of changes to certain parameters, allows for an analysis of the links between potential observables. For example, what are the possible impacts on total FLW in the value chain following loss abatement by intermediaries? Does FLW in percentage and absolute terms decrease or increase? Under what circumstances would loss reduction lead to a welfare gain or loss to farmers and consumers?

The model for each actor along the value chain

I. Farmers

The farmer makes decisions with respect to the quantity of product potentially available for sale, y , and the percentage of that potential quantity that is finally sold, α. Note that by definition, the share of food/farm output that is lost is $(1-\alpha)$. Also note that this is the observable indicator of food loss at the farmer level that the Sustainable Development Goals (SDG 12) are seeking to monitor. The producer combines various factors of production, represented by x, together with a given endowment of land capital and other fixed factors, to produce the potential level of production and the proportion sold. These resource allocations are made in an economically efficient manner (from the perspective of the decision-maker) given the prices (i.e. the opportunity costs) of those factors, represented by w, and the limits imposed by what is technically feasible, i.e. the technology. Given a transformation function $F(y,x,\alpha)$ that reflects what is physically possible, the production possibility set that restricts the possible combinations of y, $\alpha$and inputs x , is given by $F(y,x,\alpha) \leq 0$, with which the farmer's associated cost function can be defined as:

$$c(w,y,\alpha) = \min_{x}\{w^{'}x \mid F(y,x,\alpha) \leq 0\} \tag{1}$$

Realistically, for almost all farmers there is a price per unit of product sold, p_f, that is independent of individual production decisions. As a good approximation to a farmer's objective in making decisions, the optimal levels of y and α given input prices and available fixed factors are those that maximize profits or net revenues, which can be characterized using the following profit function:

$$\pi(p_f,w) = \max_{y,\alpha}\{p_f\alpha y - c(w,y,\alpha)\} \tag{2}$$

The decision rules for maximizing net revenues are simply that the marginal benefits of an additional unit of potential production (y) or proportion sold (α) are equal to their marginal costs:

$$p_f\alpha^* = \frac{\partial c(w,y^*,\alpha^*)}{\partial y} \quad \& \quad p_f y^* = \frac{\partial c(w,y^*,\alpha^*)}{\partial \alpha} \tag{3}$$

Some algebraic manipulation shows that these conditions imply that the elasticities of cost with respect to y and α are equal, and both are equal to the revenue-to-cost ratio:

$$\frac{p_f\alpha^* y^*}{c(w,y^*,\alpha^*)} = \frac{y^*}{c}\frac{\partial c}{\partial y} = \frac{\alpha^*}{c}\frac{\partial c}{\partial \alpha}$$

Although the model here separates potential production and loss abatement, as a practical matter the farmer is determining an effective supply $q_f = \alpha y$. This effective quantity is that which one can observe in market transactions.

PROPOSITION 1: Total marketed output, or effective supply, $q_f = \alpha y$ is non-decreasing with output price p_f.

This is a straightforward application of Hotelling's lemma in the context of this model. A complete proof is provided in the mathematical appendix, but this proposition relies on the convexity of the profit function. If profits can be maximized, then the profit function must be convex in (p_f, w). From Hotelling's lemma it is known that $\frac{\partial\pi(p_f,w)}{\partial p_f} = q_f(p_f, w)$, and furthermore, convexity guarantees that $\frac{\partial^2\pi(p_f,w)}{\partial p_f \partial p_f} = \frac{\partial(\alpha y)}{\partial p_f} \geq 0.$

Of more interest to an understanding of what drives foods losses at the farm level is the individual response of potential output (y) and the marketed share (α) to changes in prices.

PROPOSITION 2. The proportion of output losses $(1-\alpha)$ can increase as a response to rising farm output price (p_f), if the elasticity of the marginal cost of potential supply with respect to scale is sufficiently low and the marginal cost of loss abatement $(\frac{\partial c}{\partial \alpha})$ is increasing with scale.

In the appendix it is shown that $d\alpha/dp_f$, can be negative only if this condition is met:

$$c_{yy}y + \alpha p_f < \alpha c_{\alpha y}$$

or in terms of elasticities, $\varepsilon_{yy} + 1 < \varepsilon_{y\alpha}$,

where standard notation is used, i.e. $c_{yy} = \frac{\partial^2 c}{\partial y \partial y}$, $c_{\alpha y} = \frac{\partial^2 c}{\partial \alpha \partial y}$, and elasticity $\varepsilon_{\alpha y} = \frac{\partial^2 c}{\partial \alpha \partial y}\frac{y}{\partial c/\partial \alpha}$.

Notice that unlike most cost elasticities, in this case cross elasticities $\varepsilon_{y\alpha}$ and $\varepsilon_{\alpha y}$ are equal. From the first order conditions of profit maximization, $p_f = c_y/\alpha = c_\alpha/y$, and with Young's theorem, $c_{\alpha y} = c_{y\alpha}$; hence, the cross elasticities of marginal cost are equal: $c_{\alpha y}y/c_\alpha = \varepsilon_{\alpha y} = \varepsilon_{y\alpha} = c_{y\alpha}\alpha/c_y$.

Two forces are at play in PROPOSITION 2. If the supply elasticity of potential output (y) is low (i.e. c_{yy} is high), then the economic incentive would be to respond to price hikes with an increase in effective output (αy) via reducing losses (increasing α), more than via increases in potential output. If the marginal cost of loss abatement is decreasing with scale, $c_{\alpha y} < 0$, then higher loss abatement will always be the optimal way to increase effective output in response to a higher sales price. However, if the marginal cost of loss abatement is increasing with scale, and potential output elasticity is sufficiently low then effective output will rise while percentage *losses are increasing!*

The previous paragraph highlights the key role played by the sensitivity of the marginal cost of loss abatement with respect to scale in determining losses at the farm level. In general, if one believes that the productive process can be easily scaled up, then the marginal cost of loss abatement would display a low sensitivity with respect to scale, and scale expansion would likely be accompanied with percentage loss reduction. If there are technologies that are available at larger scales which are loss-reducing, then one would expect that $c_{\alpha y} < 0$, guaranteeing that expansions in effective supply are always accompanied with loss reductions.In agriculture, however, there are many scale-driven changes in technology that are loss increasing. The most conspicuous among them is the substitution of labour with capital intensive technologies that increase percentage losses. A good example mentioned previously is moving from hand-harvested tomatoes, to mechanized harvesting, a move that clearly increases losses from the handling of the fruit, but is economically viable, because it is accompanied with a large increase in productivity (i.e. a large rise in y). In this case, the marginal cost of loss abatement is increasing with scale, and α can fall while the marketed supply (αy) is rising. This is likely true in vegetable and horticultural crops where a move from small-scale labour-intensive cropping to industrial production is accompanied by increases in losses driven by mechanical damage, which then has led to the development and adoption of varieties less susceptible to damage.

PROPOSITION 3. Even if the share of losses declines with a price increase (α rises), total losses in terms of quantity can still increase when there is a sufficiently high output response.

Notice that total losses are defined by $l_f = (1-\alpha)y$. The effect on total losses is the sum of the effects on loss abatement and on the level of potential production:

$$\frac{dl_f}{dp_f} = \frac{dy}{dp_f}(1-\alpha) - \frac{d\alpha}{dp_f}y = \frac{dy}{dp_f} - \frac{d(\alpha y)}{dp_f}$$

It has already been shown that effective supply rises with an increase in price, PROPOSITION 1, so total losses can increase as a result of a hike in prices if the response of potential output to price increases, which is $\frac{dy}{dp_f}$, is sufficiently high.If it is assumed that the marginal cost of loss abatement is not responsive to scale, $c_{\alpha y} \approx 0$, then as shown above, the share of losses will be reduced, $\frac{d\alpha}{dp_f} > 0$. However, total losses can still increase, $dl_f/dp_f > 0$ if:

$$\frac{(1-\alpha)}{\alpha}(\varepsilon_{\alpha\alpha}+1) > (\varepsilon_{yy}+1)$$

that is when share of losses are high $(\alpha \to 0)$ and/or $\varepsilon_{\alpha\alpha} > \varepsilon_{yy}$, marginal costs of abatement rise faster than marginal costs of potential production.

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II. Intermediaries

Most of the attention to the problem of FLW has focused on post-harvest activities, storage transport, processing, retail, and final household consumption. The intermediary node of the agrifood system has drawn particular attention in the context of developing countries. There is, however, no reason to think that agents would be less attentive to their own interests – and more wasteful – at this stage than at any other stage of the food value chain. As at other stages, agents respond to changing prices (both at the farm gate and the retail level) and adopt productivity and FLW choices in response to these incentives within technological constraints.

The intermediary makes decisions with respect to the quantity of the product purchased from the farmer, q_f, and the potential quantity offered to buyers q_I, and the proportion of this potential that is effectively delivered to buyers, $0 < \beta \leq 1$, at a price p_b. In general, there will be some transformation that takes place between q_f and q_I, as would be the case of transforming wheat grain into flour. As with the farmer, one should assume that the intermediary combines various factors of production, x, in an economically efficient manner, given both an initial quantity purchased from the farmer (q_f) and input prices w, so as to produce the final proportion sold (βq_I). Given a transformation function $G(x, q_f, q_I, \beta)$, the production possibility would be defined by $G(x, q_f, q_I, \beta) \leq 0$, with which one can define the intermediary's associated cost function, conditional on the farm input purchased:

$$\kappa(w, q_f, q_I, \beta) = \min_{x}\{w' x \mid G(x, q_f, q_I, \beta) \leq 0\} \tag{4}$$

Unless they are monopolies or monopsonies, intermediaries would be price-takers, responding to prices per unit of the product purchased from the farmer, p_f, and of the product sold to the buyer, p_b. The optimal levels of q_f, q_I, and β would be chosen to maximize net revenues:

$$\Pi\ (p_b, w, p_f) = \max_{q_f, q_I, \beta} p_b \beta q_f - \kappa(w, q_f, q_I, \beta) - p_f q_f$$

Although the above setup is valid in general, both the literature (see for example Bellemare ***et al***., 2017; Koester, 2014; Parfitt ***et al***., 2010, among others), and organizations concerned with tracking SDG 12 (see for example Fabi and English, 2018; Stenmarck ***et al***., 2016) are focused on providing agrifood-system-wide aggregate measures of percentage losses, based on quantities that are aggregated across system nodes. The idea of aggregating quantities along the value chain is dubious from an economic point of view, as argued in Anriquez ***et al***. (2018). However, if one wants to aggregate quantity losses at different nodes of the agrifood system, they should ideally follow a physically comparable product (such as a fresh tomato in the farmer's field and a fresh tomato in the supermarket bin). Otherwise, how could one aggregate loss from discarded juice at a household with grape losses during transport to a juice processing plant? Hence, the minimal assumption necessary to compare and aggregate losses at different nodes, is that product transformation can be approximated by a fixed coefficients technology:

$$q_I = a \cdot q_f \qquad (5),$$

which obviously ignores any possible substitutability in production and transformation processes. For the purpose of the following presentation, in order to allow explicitly for quantity aggregations, fixed proportions technology is assumed, and to reduce algebraic clutter, it is assumed that $a = 1$. These assumptions remove one of the choice variables, and can simplify the intermediary's problem with these simplified equations:

$$\begin{gathered}\kappa(w, q_f, \beta) = \min_{x}\{w^{'}x \mid G(\,x, q_f, \beta) \le 0\} \\ \Pi\ (p_b, w, p_f) = \max_{q_f,\beta} p_b \beta q_f - \kappa(w, q_f, \beta) - p_f q_f\end{gathered} \tag{6}$$

The decision rules for maximizing net revenues are met when the marginal benefits of an additional unit of potential production or proportion sold are equal to the marginal costs:

$$p_b\beta^* = \frac{\partial\kappa(w, q_f{}^*, \beta^*)}{\partial q_f} + p_f \quad \& \quad p_b q_f{}^* = \frac{\partial\kappa(w, q_f{}^*, \beta^*)}{\partial\beta} \tag{7}$$

As with the case of the farmer, a little algebraic manipulation shows that these conditions imply that the elasticities of total cost with respect to q_f and β are equal, and equal to the revenue-to-cost ratio:

$$\frac{p_b\beta^* q_f^*}{\kappa(w, q_f, \beta) + p_f q_f} = \frac{q_f{}^*}{\kappa + p_f q_f}\left(\frac{\partial\kappa}{\partial q_f} + p_f\right) = \frac{\beta^*}{\kappa + p_f q_f}\frac{\partial\kappa}{\partial\beta}. \tag{6}$$

PROPOSITION 4. If the price of the food input increases, intermediaries will always demand less of the farm product.

The sign of the derivative of quantity of farm product demanded with respect to its price (dq_f^*/dp_f) is given by $(-\kappa_{\beta\beta})$, which is positive at a point of maximum profit. As in the case of potential output, the profit maximizer will not choose quantities in the range of declining marginal costs, because the same first-order condition is met at higher output levels with higher profits.

PROPOSITION 5. If the marginal cost of loss abatement is independent or decreasing with scale, an increase in the price paid to farmers will increase the loss proportion by intermediaries.

To see this, note that at the optimal level of loss-abatement, $p_b q_f = \kappa_\beta$, and that the sign of the derivative of share of losses of potential output with respect to farmer price $(d\beta^*/dp_f)$ is given by $[-(p_b - \kappa_{\beta q_f})]$. The proportion lost during the intermediary stage depends on the sensitivity of the marginal cost of loss abatement with respect to scale:

$$\frac{d\beta}{dp_f}\ \left\{\begin{array}{ll}\ge 0 & \text{if } \epsilon_{\beta q_f} > 1 \\ < 0 & \text{otherwise}\end{array}\right.$$

where, again, elasticities follow standard notation, i.e. $\epsilon_{\beta q_f} = \frac{\partial\kappa_\beta}{\partial q_f}\frac{q_f}{\kappa_\beta}$. Further, note that elasticities are, like in the case of the farmer, also symmetrical: $\epsilon_{\beta q_f} = \epsilon_{q_f\beta} = \frac{\partial\kappa_{q_f}}{\partial\beta}\frac{\beta}{\kappa_{q_f} + p_f}$.

Thus, if the marginal cost of loss abatement is sufficiently low or (likely) approximately independent from scale, $\kappa_{\beta q_f} \approx 0$, then β would fall, i.e. losses would increase as a result of an increase in farm gate price. This may appear a surprising result initially, but when the farm gate price falls, the marginal benefit of loss abatement, in terms proportion $(p_b q_f{}^*)$ also falls indirectly:

$$\frac{\partial MB(\beta)}{\partial p_f} = p_b \frac{dq_f^{\,*}}{dp_f} < 0$$

An important implication of this proposition is that productivity gains at the farmer level which translate into lower farm gate prices would unintentionally translate into a positive spillover in terms of a reduced share of food losses at the intermediary stage.

However, in general, the parameter, $\kappa_{\beta q_f}$, that relates how the marginal cost of loss abatement changes with scale, may take any sign. Nevertheless, for goods whose physical quantities can be followed along the value chain, it is difficult to argue that this parameter should be positive and large. For example, consider the pasta value chain: wheat is transformed into flour, and flour is processed into spaghetti at a fixed rate. In this case, it is hard to think that the marginal cost of producing pasta can fall with an increase with the proportion of flour lost. It is reasonable to expect that, in the case of most intermediary firms where the transformation of physical produce is approximately fixed-proportion, as the price of the food input increases, percentage losses should increase as well, $\frac{d\beta^*}{dp_f} < 0$.

PROPOSITION 6. Although percentage losses increase with a rise in the food input price, the effect on total losses is ambiguous. Furthermore, they will be positive in the case of the "efficient" intermediaries.

As shown in the appendix, the effects of an increase in the food input price on total losses in the intermediary stage, $l_b = (1-\beta)q_f$, are given by

$$\frac{dl_b}{dp_f} = \frac{dq_f}{dp_f}(1-\beta) - \frac{d\beta}{dp_f} q_f = -\frac{\kappa_{\beta\beta}}{\mathrm{D}}(1-\beta) + \frac{p_b - \kappa_{\beta q_f}}{\mathrm{D}} q_f$$

where D is a positively signed matrix determinant (see the appendix), the sign of which depends, again, on the relative sensitivity of the marginal cost of loss abatement to both scale and the level of loss abatement. Noting from the assumption of a profit-maximizing intermediary that, $p_b q_f = \kappa_\beta$ one finds

$$\frac{dl_b}{dp_f} \; \{ \begin{array}{ll} \geq 0 & \text{if } \epsilon_{\beta q_f} + \epsilon_{\beta\beta}\dfrac{1-\beta}{\beta} < 1 \\ < 0 & \text{otherwise} \end{array}$$

Note that the first term on the right-hand-side is the cross elasticity of the marginal cost of loss abatement with respect to scale, and the second term represents the own-elasticity of the marginal cost of loss abatement with respect to an increase in the abatement level. Again, as in the case of the proportion of losses, with an increase of food input price, the level of product moving through the intermediary stage will decrease, diminishing the marginal benefit of loss abatement. If the marginal cost of loss abatement is insensitive or perhaps declining with scale, the abatement level would fall in order to re-equilibrate the marginal cost of abatement with its marginal benefit. If the marginal cost of abatement is sufficiently insensitive to the abatement level, then total losses would increase. The reader will note that "sufficiently" insensitive depends on the optimal level of abatement from which the comparison is made $(\frac{1-\beta}{\beta})$. If losses are already approaching zero $(\beta \approx 1)$, then unless the elasticity of the marginal cost of abatement $(\frac{\kappa_{\beta\beta}}{\kappa_\beta}\beta)$ is approaching infinity, total losses will increase with an increase in the food input price.

PROPOSITION 7. Effective supply of the intermediate good $q_b = \beta q_f$, does not decline with a rise in the selling price of the intermediary, p_b.

As with Proposition 1, this is a straightforward application of Hotelling's lemma in the context of the intermediary. Profit maximization implies that the profit function $\Pi\ (p_b, w, p_f)$ would be convex in (p_b, w, p_f). Hotelling's lemma states that $\frac{\partial \Pi\ (p_b,w,p_f)}{\partial p_b} = q_b$, and convexity ensures that $\frac{\partial q_b(p_b,w,p_f)}{\partial p_b} = \frac{\partial^2 \Pi\ (p_b,w,p_f)}{\partial p_b \partial p_b} \geq 0.$

PROPOSITION 8. An increase in the sales price reduces the share of food loss when the marginal cost of loss abatement is independent or falls with scale of production.

As shown in the appendix, the sign of $d\beta/dp_b$ is given by the sign of the expression $\kappa_{q_f q_f} q_f + (p_b - \kappa_{q_f \beta})\ \beta$, which, after noting the first-order conditions $p_b q_f = \kappa_\beta$ and $p_b \beta = \kappa_{q_f} + p_f$, can be rewritten in terms of elasticities:

$$\frac{d\beta}{dp_b}\ \begin{cases} \geq 0 & \text{if } \epsilon_{q_f q_f} - \epsilon_{\beta q_f} + 1 > 0 \\ < 0 & \text{otherwise} \end{cases}$$

The first term on the right-hand-side of the equation represents the elasticity of marginal costs of scale with respect to an increase in potential production, and the second term represents the cross elasticity of the marginal cost of loss abatement with respect to scale. In the (reasonable) case that the response of the marginal cost of loss abatement to increases in scale is either small or negative, the term $d\beta/dp_b$ is certainly positive and yields the expected result that when the price of the marketed good increases it is handled with greater care, and the percentage losses as a result are reduced.

PROPOSITION 9. Even if percentage losses decline, sales price increases can lead to a rise in total losses if the marginal cost of loss abatement increases sufficiently rapidly with loss reductions.

The change in total losses at the intermediary stage due to an increase in the product price, p_b, is given by

$$\frac{dl_b}{dp_b} = \frac{dq_f}{dp_b}(1-\beta) - \frac{d\beta}{dp_b} q_f$$

As is shown in the mathematical appendix, the sign of this expression can be shown to be determined, using cost elasticities, by the sign of the following expression:

$$(1-\beta)\,(\epsilon_{\beta\beta} + 1 - \epsilon_{\beta q_f}) - \beta\,(\epsilon_{q_f q_f} + 1 - \epsilon_{\beta q_f})\ .$$

The above expression shows that even if the share of losses is reduced as result of increasing sale price, total losses can increase when the share of losses are low $(\beta \to 0)$, and/or the marginal cost of loss abatement rises rapidly with loss reductions, i.e. $\epsilon_{\beta\beta}$ is sufficiently high.

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III. Buyers/final consumers

The final consumption of food in the home involves two activities: purchasing the basic materials and ingredients for meals (the food inputs), which requires monetary expenditure, and preparing the meals, which inevitably requires expenditure on additional resources, including, importantly, human time. Decisions regarding the purchase and use of food and the preparation of meals will be influenced by the opportunity cost of time. Food waste occurs when basic materials and ingredients are not used in a sufficiently careful or timely way when being transformed into meals, although the definition of “sufficiently careful or timely” is likely highly subjective. The amount of ingredients purchased in the market would give an upper bound to the satisfaction or utility the household can derive from the meals finally produced, but it is not costless to reduce waste. Waste reduction requires greater frequency in going to the market and the reduction of spoilage of perishables, or more care in food preparation, such as more attentive handling, preparation of longer-lasting meals, more careful portioning, etc. How much time and effort households devote to reducing waste depends on the costs of the basic food materials relative to their opportunity cost of time. In modelling the case of the consumer, it would be more useful to address the trade-offs between food inputs and household time via a ‘primal’ approach. This will allow an explicit view of optimal food loss at the household level, because lower losses are primarily a result of a greater allocation of household time in terms of the effort required to buy and prepare food (Ellison and Lusk, 2018).

In the following household time-allocation model, a simplified approach is taken with consumer utility depending on three types of goods consumed in a period of time: food consumed as meals or nutrition f, the time dedicated to leisure, h , and the units of a composite of other goods z (taken as the numeraire). The consumer can allocate total time available in the period, T, to leisure time, to food preparation time, k, and to time dedicated to income-generating employment, represented as $(T - h - k)$and which has an associated wage, w. The amount of the final food consumed, f, is a function of the food purchased from an intermediary, q_b, and the food preparation time, k: $f = f(k, q_b)$. To reduce the algebraic complexity of the problem, the quantity of food consumed is taken to be measured in the units of the basic food purchased and so the proportion of food consumed of the total purchased can be presented as $\gamma = f/q_b$, and the proportion of food “wasted” at the household level as $1 - \gamma$. The consumer’s optimization problem is to assign leisure, employment and food-preparation time and expenditures on food and other goods so as to maximize utility subject to time and budget constraints and to the household food-production function:

$$V(p_b, w) = \max_{q_b, z, l, k, f} U(f, h, z) + \mu_1[f - f(k, q_b)] + \mu_2[w(T - h - k) - p_b q_b - z] \quad (7)$$

First, note that the opportunity cost (the price) of time in food preparation, as in the case of leisure, is simply given by the wage, w, and so the first interesting condition for optimization is that the rate of technical substitution between preparation-time, k, and the food purchased, q_c , is equal to the ratio of prices:

$$\frac{f_k}{f_{q_b}} = \frac{w}{p_b} \quad (8)$$

where $f_i = \frac{\partial f}{\partial i}$. Of interest are changes in the level of food waste due to changes in both the price of the basic food and wages. As shown in Anriquez ***et al***. (2018), it is possible that when incomes are very low, and the quantities of meals (or nutrition) are correspondingly low, a reduction in the price of food input would be accompanied by a reduction in the observed proportion of food wasted. This result is driven by a high and slowly declining marginal utility of meals/nutrition, and the income effects of the reduction of the basic food input price, which induces the nutritionally unsatiated household to increase its consumption of food, f, both by redirecting time from employment to household effort in food loss reduction k, and to purchasing more food input, q_b.

Here the focus is on the more familiar case of when meals/nutrition consumed rise slowly or are insensitive to income changes, which is likely the case relevant in countries where household food waste is of concern. In this scenario, where the final food consumption level is relatively stable, which would be the case when consumers have reached adequate caloric and nutritional levels, one can draw certain sharp results. While price and income changes would influence the composition of food expenditures (such as the frequency of restaurant visits, the quality of food products, etc.), the basic nutritional characteristics of meals (such as total calories) for the representative consumer are likely to remain relatively unchanged. The change in food-as-meals, f, is made up of a change in kitchen/preparation time, k, and a change in the basic food input, q_b. This condition can be written, as $df = f_k dk + f_{q_b} dq_b$, or after a little algebraic manipulation,

$$dk = \frac{1}{f_k} df - \left(\frac{f_{q_b}}{f_k}\right) dq_b \, . \tag{9}$$

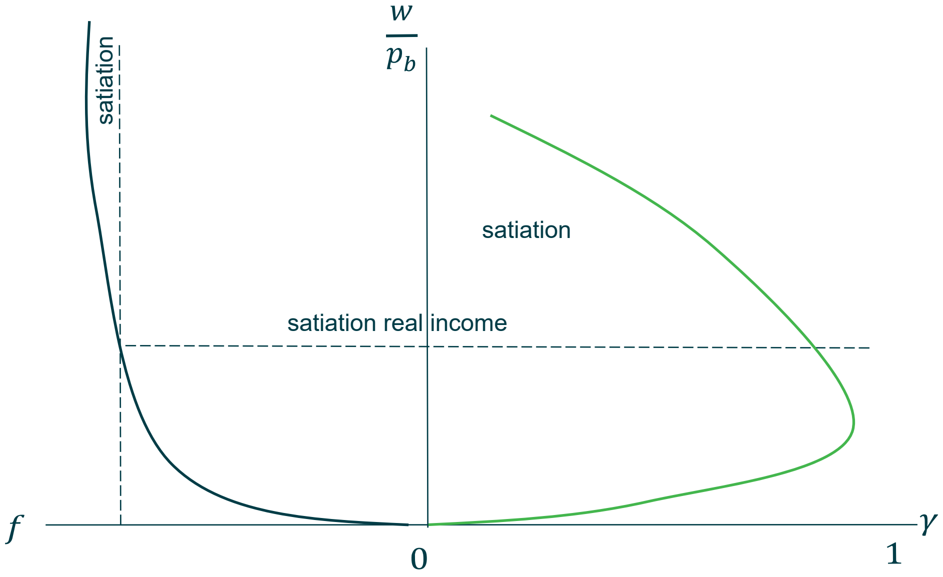
If the food finally consumed is roughly unchanged, $df \approx 0$, using (8) results in:

$$dk \approx -\left(\frac{f_{q_c}}{f_k}\right) dq_b = -\left(\frac{p_b}{w}\right) dq_b . \tag{10}$$

Relationship (10) establishes that there is an inverse relationship between household effort in food waste abatement and the real price of food. For example, wage increases, which increase household real income, would be accompanied with less effort relative to increases in the food input purchased. Also note, that relationship (10) shows that, as explained above, an increase in the price of food would lead to an increased effort in food preparation only if there is a high response in the consumption of meals/nutrition (df), which would be the case in a severely nutritionally-unsatiated household.

Figure 2.1 illustrates the relationship between food waste and wages and prices. As real income increases, the quantity of meals/nutrition consumed increases at a decreasing rate, eventually reaching a point of satiation (when the rate of change is approaching zero). If real income is zero, and there is no food input purchase, there is no reason to spend any effort in waste reduction and γ is equal to zero. As real income increases (either because wages increase or the price of food decreases) the benefit of food loss reduction increases faster than the cost, and therefore, effort invested in food waste abatement increases. Eventually, with satiation, the trade-off in household food production between time k and the food input q_b begins to dominate, and any increase in real income is accompanied with increases in optimal levels of food waste.

Figure 2.1 **The relationship between real income (w/p_b), food waste $(1-\gamma)$, and meals/nutrition consumed (f)**



PROPOSITION 10a. Waste abatement will increase with an increase in the price of the food input, if the price elasticity of the final food consumed (meals) is less in absolute value than the price elasticity of the market demand for food products.

By definition of gamma $\gamma = f/q_b$, one can easily obtain this relationship in terms of elasticities,

$$\frac{d\ln\gamma}{d\ln p_b} = \frac{d\ln f}{d\ln p_b} - \frac{d\ln q_b}{d\ln p_b} \tag{11}$$

which proves Proposition 10a. This proposition simply states that the food-satiated consumer will increase their share of food wasted as, ceteris paribus, the price of food declines, or as the wage increases. The flipside of this proposition is:

PROPOSITION 10b. Over the range of real income where food waste increases with real income, the demand for food purchased, q_b, is downward sloping in terms of prices paid.

This proposition is simply equation (11) after isolating the elasticity of food purchases on the left-hand side. A corollary to this proposition is that the hypothetical Giffen good is possible when γ falls with increases in the real price of purchased food at a faster rate than the decrease in meals/nutrition.

Market equilibrium and comparative statics

The total FLW measured within the whole agrifood system is the result of individual decision-makers' optimizing decisions in response to prices, which are the coordinating mechanisms that bring distinct actors in the market chain into agreement about the quantities of food produced, exchanged and consumed. Changes in technology or prices of other inputs, or changes in consumer incomes, or changes in the prices of non-food goods will all have their individual effects on the optimal levels of FLW, the optimal levels of goods available for exchange, and the optimal levels finally consumed as meals. A change to, say, the available technology at one point along the value chain that alters the relative scarcity of the potential food available will be communicated via prices to other actors up and down the agrifood system, inducing changes to the use of resources dedicated to loss and waste abatement well beyond where the technological change has taken place. An exogenous shift downward in the marginal cost of loss abatement at an upstream point in the value chain would be, certainly in competitive markets, communicated to buyers downstream to final consumers through lower food prices, which would likely signal that fewer resources should be directed to waste reduction.

To further develop the logic regarding the market equilibrium effects, consider the case of a reduction in food losses at the intermediary stage. To focus on the link between equilibrium prices and FLW, a useful simplification of the model of intermediaries/processing/transport is to assume that the intermediary sector is competitive with free entry and exit and that all participants make use of the same cost-minimizing technology. In this case, the relationship between final buyers' prices, p_b, prices paid to producers, p_f, transport/transformation costs, t, and the cost-minimizing level of the marketed percentage, β, is given by the zero-profit condition: $p_b\beta - p_f = t$.

This relationship can also be rewritten in terms of the standard straightforward observable marketing margin:

$$m = p_b - p_f = \frac{1-\beta}{\beta} p_f + \frac{1}{\beta} t \geq t$$

In this competitive-equilibrium case, there will be a simple relationship between changes in a decrease in percentage losses at the intermediary level (and increase in β) and the marketing margin. Taking the basic zero-profit condition,

$$\beta dp_b + p_b d\beta - dp_f = 0$$

and rearranging terms, one finds,

$$\frac{\mathrm{dln}p_b}{\mathrm{dln}\beta} + 1 = \frac{\mathrm{dln}p_f}{\mathrm{dln}\beta} \frac{p_f}{\beta p_b}$$

The impact of a decrease in losses at the intermediary level, therefore, can lead to an increase or a decrease in the farmers' price, depending on whether the buyers' aggregate demand for the good is elastic or inelastic. This is a relatively straightforward extension of a result found in the literature on the welfare effects on producers of productivity gains (this has been discussed within the context of 'Cochrane's treadmill,' e.g. Alston (2018).

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Market equilibrium under the above conditions is represented in Figure 2.2. The supply and demand curves are given by the solid lines. The supply is the marginal cost curve at the farm level, MC(q_f), in terms of the quantity of product sold by producers to intermediaries, q_f. The consumer demand is given by the marginal benefits curve, MB (q_b), in terms of the quantity of the product bought by consumers from intermediaries, q_b. The percentage of losses in the intermediary stage is $(1-\beta)$ and so equilibrium prices at the farm gate, p_f , and paid by consumers, p_b, must be such that $q_b = \beta q_f$. Given a competitive intermediary sector ($p_b\beta = p_f + t$), the equilibrium quantity sold by producers, q_{f0} , is therefore given by: MB $(\beta q_{f0}) = \frac{1}{\beta}$ (MC $(q_{\ 0}) + t$).

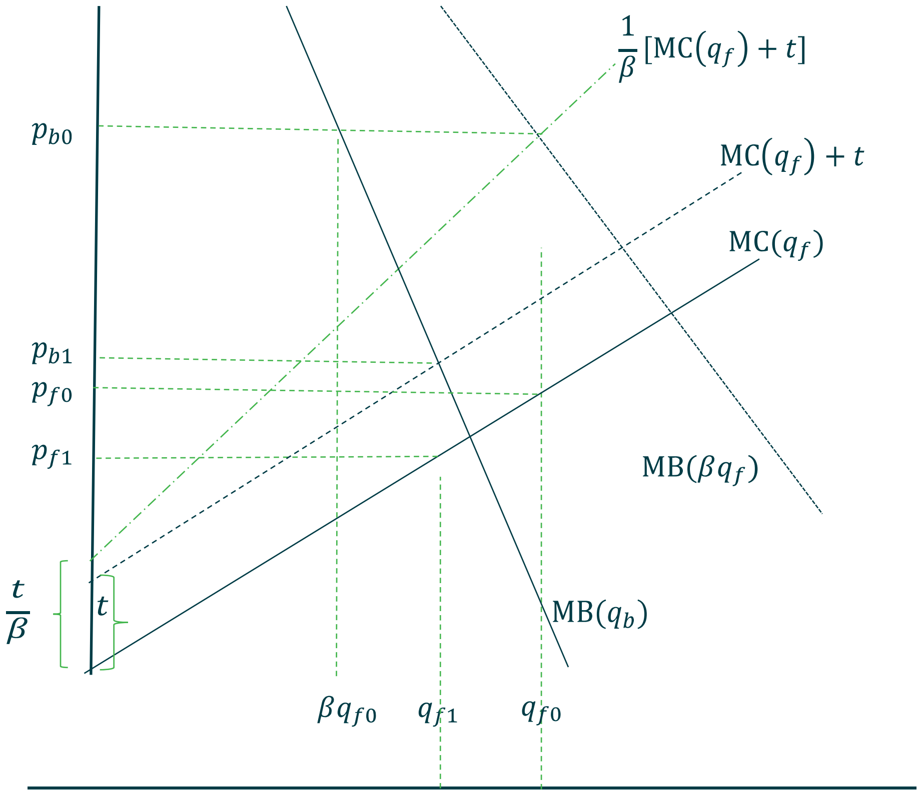
In Figure 2.2, the curve MB (βq_f) represents the marginal willingness-to-pay of the consumers for another unit of the product in terms of the farm-gate units of the product; and the curve $\frac{1}{\beta}(\mathrm{MC}(q_f) + t)$ represents the effective supply of farmers' products in terms of the price paid by consumers. The intersection of these two curves define the equilibrium prices paid by the consumer, p_{b0} , and received by the producer, $p_{f0} = p_{b0}\beta - t$, and the equilibrium quantities sold at the farm gate, q_{f0} , and purchased by consumers, $q_{b0} = \beta q_{f0}$.

The impact of a decline in losses at the intermediary stage is illustrated by setting $\beta = 1$, which represents the extreme case of eliminating food losses in the intermediary stage altogether. In the case of the market represented in Figure 2.2, because of the steepness of the demand curve (the initial equilibrium occurring in the inelastic portion of the curve), there is not only a decrease in the consumer's price (from p_{b0} to p_{b1}) but a decrease in the price received by the producer (from p_{f0} to p_{f1}). Under the likely conditions of well-off consumers discussed in the section on consumers above, and regardless of the degree of elasticity of the market demand for food, the fall in consumer prices will lead to an increase in food waste at the household level, at least partially off-setting the reduction in food losses at the intermediate level. As discussed in the section on decisions at the farm level, whether losses also increase at the farm level depends on the relationship between production scale and the marginal cost of loss abatement.

As a result of an exogenous decrease in losses at the intermediary level, the final change in total FLW along the value chain, both in terms of sign and order of magnitude, is ambiguous. Under what conditions could total FLW increase, decrease or remain unchanged? To answer this question, define the share of food produced by farmers that is finally consumed as $\varsigma = \alpha\beta\gamma$, and so the total share of FLW in the system is $(1-\varsigma)$ and the total quantity of FLW is $(1-\varsigma)q_f$. Under the conditions of the market equilibrium discussed in the context of Figure 2.2, the impact on the rate of total loss abatement of an increase in β is, in terms of elasticities is:

$$\frac{d\ln\varsigma}{d\ln\beta} = \frac{d\ln\alpha}{d\ln p_f}\frac{d\ln p_f}{d\ln\beta} + \frac{d\ln\gamma}{d\ln p_b}\frac{d\ln p_b}{d\ln\beta} + 1. \qquad (12),$$

Figure 2.2 Market equilibrium of the three value chain actors



Although expression (12) may even take a negative value, one can provide an informative approximation making some reasonable assumptions. Starting with the consumer, and assuming a downward sloping demand curve which occurs for the well-off consumer (see Proposition 10b), then the equilibrium condition is $q_b = \beta q_f$. It follows then that $\frac{d\ln p_b}{d\ln\beta}$ is negative, because for the consumer a rise in β is observed as an increase in supply (see Figure 2.2). Furthermore, as shown in Proposition 10a, increases in consumer prices are accompanied by increased consumer waste, $\frac{d\ln\gamma}{d\ln p_b} > 0$. The first term in (12) is ambiguous but depends on consumer preferences and farm technology. In particular, if consumer demand is inelastic, as shown in Figure 2.2, the fall in demand implied by reduced losses at the intermediary stage may be accompanied by a reduction of farm-gate prices, $\frac{d\ln p_f}{d\ln\beta} < 0$. . The response of loss abatement on the farm to an increase in farmer prices is ambiguous as discussed above; however, in the "normal" case where losses are reduced with scale, then $\frac{d\ln\alpha}{d\ln p_f}$ is certainly positive. Hence, under fairly innocuous conditions, one would expect $\frac{d\ln\varsigma}{d\ln\beta}$ to be less than one. This means in practice that total losses fall proportionally less than the exogenous reduction in losses at the intermediary level. The reader will note that this expression, under some extreme conditions, could be negative. This would be the case when consumer waste is highly responsive to prices, when consumer demand is very inelastic, or when the farmer's loss response is highly sensitive to changes in farm-gate prices.

Conclusions

This chapter provides a simplified but useful economic model to understand the relationships between FLW and incentives, and how choices relevant to FLW at one stage of the food value chain would, via prices, affect decisions in other nodes. The model is based on basic microeconomic theory and makes few assumptions regarding the nature of production (technology) and consumer behaviour (preferences). The insights and implications of this modeling effort can help guide empirical and econometric work, as well as policymaking.

This type of modelling effort highlights the important 'observables' that policy analysts should be tracking in order to understand how price and productivity changes translate into changes in optimal loss decisions at the different nodes of the food value chain. In particular, the model shows that the response of the marginal cost of loss abatement to changes in scale is a key technological factor that determines optimal FLW decisions. Seen in terms of production decisions, the response of relative losses to changes in scale is a key determinant of the response of farmers to changes in incentives (i.e., farm gate prices). The consumer, particularly in food value chains where intermediaries perform in competitive markets, plays an important role in determining the effects of productivity changes at the level of producers and intermediaries on total relative and absolute losses. The consumer demand elasticity of food consumed, and the response of consumer waste to prices and income are key indicators of the impact of productivity changes on food losses generated along the value chain. Although the model does not provide definitive answers to some key policy questions, it does narrow the relationships and parameters that need to be observed in order to make reasonable and informed predictions.

The model provides some important guidance for policymaking. Reducing losses at a particular node of the food value chain in practice is equivalent to increasing productivity at that same node. This understanding links the FLW analysis to a more developed and studied literature which has examined how productivity changes disseminate across actors in the value chain, e.g. Alston (2018). It also highlights that in order to obtain desired outcomes, policymakers need to understand the nature of food value chains. For example, the model shows that reducing losses at the intermediary stage would likely increase food waste downstream at the consumer stage, and, under reasonable conditions, increase harvest and post-harvest losses at the farm. The model also provides insight on the challenges to reducing household waste given incentives, and the role of income and food prices in household food waste reduction.

03

Empirical analyses of food losses at the farm level. Three examples from Tunisia and Egypt

As discussed in previous chapters, most of the literature analysing FLW separates losses at different stages or nodes of the food value chain. The majority of studies differentiate between losses occurring at four different stages of food supply systems: growers, processors, retailers and consumers (see Bellemare ***et al***., 2017; FAO, 2014; FAO, 2011; Hodges ***et al***., 2011; Stenmarck ***et al***., 2016). The previous chapters, for the analytical purposes of understanding decision-makers' responses to incentives, and following the research by Anriquez ***et al***. (2018) and Foster and Anriquez (2018), focus on three types of agents contributing to FLW: farmers, intermediaries, and final consumers. Two important implications of these modelling efforts are, first, that rates of FLW at all points along the food supply and consumption chain are influenced by the opportunity cost of resources (of which time is a key part), and, second, that research on FLW should take into consideration the relation between scale economies and the marginal costs of loss reduction.

This chapter applies the broad conceptual models developed above to an in-depth review of farm level losses in cereal and dairy farms in Tunisia and of farm and wholesale-level losses in Egyptian tomato production. Farms producing these foods are of interest because they exhibit production technologies characterized by strong economies of scale, which has implications for the efficiency of farms as measured in the general productivity literature. Chapter 1 stresses that farmers are an important node to analyse carefully, because it is not clear a priori that scale is associated with lower losses; by contrast, scale is more likely correlated with lower marginal costs of loss reduction in the case of intermediaries, where total sales values are directly linked to volumes ultimately delivered to buyers. An important feature closely addressed in this chapter is the relationship between farm scale and losses. This relationship is crucial, because, as Chapter 2 shows, with regard to the use of resources devoted to loss abatement, the farmer's response to changes in farm output prices is determined by the relationship between the marginal costs of both loss reduction and production scale expansion. In particular, when the marginal cost of loss abatement is decreasing with scale, then with certainty, the response of farmers to increasing prices is to reduce percentage losses; but if the marginal cost of loss abatement is increasing in scale, the response of percentage losses to an output price increase is ambiguous in sign, and perhaps even can increase. This is a particularly important result in the context of price determination in market systems, where changes in productivity and loss levels at specific points in the agrifood system are transmitted via prices up and down the value chain, with repercussions on loss rates elsewhere.

The chapter is in spirit of the econometric analysis proposed by Chegere (2018), estimating determinants of losses at the farm level, but also trying to disentangle the economic benefits of different loss-abating actions. As stressed in Chapter 1 and in Anriquez ***et al***. (2018), the fact that there are measured losses is not itself of economic importance. Losses are economically important if there are loss-abating actions that cost less than the benefits of implementing them. Therefore, an econometric analysis of food losses, as presented here, should attempt to quantify the economic impact of these losses.

The following section describes the cereal production sector in Tunisia, followed by a detailed analysis of the determinants of wheat losses among surveyed cereal farmers in the governorates of Bizerte and Siliana, two important grain-producing regions of the country. Then the chapter discusses the dairy-producing sector in Tunisia, and presents an analysis of milk losses among dairy farms in the governorates of Bizerte and Mahdia. The penultimate section presents an analysis of the economic rationality of reducing tomato losses in Egypt at the farm and wholesale level by the adoption of plastic crates instead of traditional palm crates. The final section provides some concluding remarks.

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Losses in cereal production in tunisia

Wheat is the main staple of Tunisia. Of the roughly 2.9 million hectares of arable land in the country, 1.25 million were devoted to cereal production in the country over the five-year period 2012-2016 (FAO, 2020b). Of the land under cereal production, 55 percent is used for wheat production and 40 percent for barley. The wheat value chain has five main nodes before reaching the final consumer: (1) farmers who harvest and collect grain, selling mostly to (2) Collection Centres (Centre de Collecte), which sort and either stock in (3) silos or sell directly to (4) semolina mills. Semolina and flour from the mills is then sold to (5a) the agroindustry that prepares mostly industrial pasta and couscous and (5b) to bakeries or boulangeries (FAO, 2020a). According to the last Agricultural Census of 2005, there are about 250 thousand farms producing cereals in Tunisia, and, remarkably, given scale economies, there are cereal producers of all sizes, as shown in Table 3.1

Table 3.1 Cereal Producers by Farm Size, 2004–2005

Farm Size (hectares)	Number	%
0–5	89 242	35.9
5–10	67 596	27.2
10–20	48 859	19.7
20–50	31 219	12.6
50–100	7 932	3.2
100 and up	3 610	1.5
Total	248 458	100

Source:

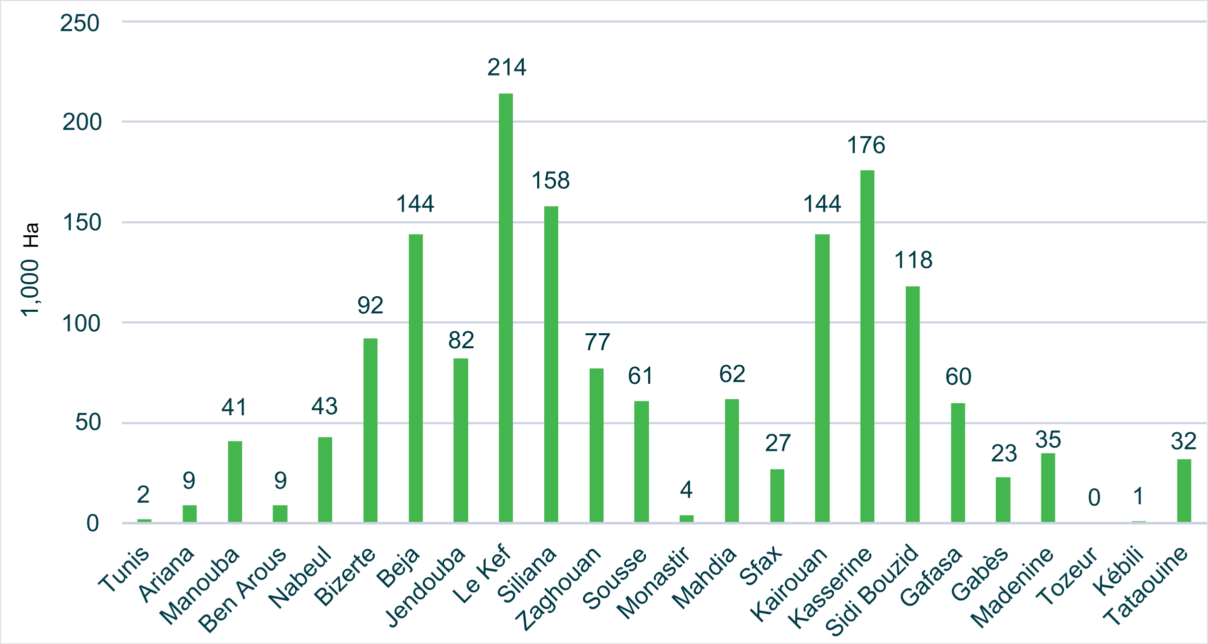
Ministère de l'Agriculture et des Ressources Hydrauliques. 2006. *Enquête sur les Structures des Exploitations Agricoles* 2004-2005. Tunis.

Collection (buying and stocking) services are currently provided by 11 private collectors, four Mutual Marketing and Agricultural Services Companies (SMSA, former cooperatives) and the public Office of Cereals (OC, Office des Céréales). The total number of accredited centres in 2017 was 200 in 16 governorates. Of these collection centres, 138 are managed by private collectors. The SMSA is present in the governorates of Zaghouan, Béja, Siliana, Jendouba and Bizerte with 54 collection centres. The OC manages eight collection centres in the governorates of Kasserine, Sidi Bouzid and Gafsa, where the lack of sufficient grain makes collection by the private sector unprofitable (FAO, 2020a). These collectors provide a storage capacity of around 7.7 million quintals, around five million from private collectors, 2.5 million by the SMSA, and about 0.2 million by the OC.

Wheat production in Bizerte and Siliana

To analyse losses in the wheat value chain, this chapter makes use of a special survey carried out by FAO in the governorates of Bizerte and Siliana. As shown in Figure 3.1, these are two of the most important governorates in terms of cereal farming land. According to the last Agricultural Census, Siliana and Bizerte had the fourth and seventh most cereal farming land by area, respectively.

Figure 3.1 Cereal production area by governorate, 2004–2005



Source: Ministère de l'Agriculture et des Ressources Hydrauliques. 2006. *Enquête sur les Structures des Exploitations* Agricoles 2004–2005. Tunis.

Bizerte is located in the northern coast of Tunisia. In the governorate, approximately 100 thousand hectares of wheat are planted each year, almost all of it rainfed, with less than one thousand hectares under irrigation. There are approximately 8000 wheat farmers in the governorate. Yields are relatively high in Bizerte, for rainfed cereal production, at approximately 24 quintals/hectare.

These yields compare favourably with yields in Kansas (26 quintals/hectare), one of the main rainfed wheat-producing states in the United States of America. The governorate has 28 grain collection centres, 21 private and seven from the SMSA, with a total capacity of 137 thousand tonnes.

Siliana is located in the centre North area of Tunisia. The governorate has one of the largest areas of wheat production in the country, consisting of 9300 farms. It plants approximately 160 thousand hectares of wheat per year, most of it rainfed, with about 2.5 percent of the area irrigated. Yields are low and more variable than in Bizerte, with averages around 13 quintals/hectare, but with bumper years where yields can jump up to 20 quintals/hectare. There are 32 collection centres in the governorate, equally distributed between private (16), and SMSA centres, with a total capacity of 126 thousand tonnes (FAO, 2020a).

Field Losses: A Case Study in Bizerte and Siliana

In an attempt to better understand losses in the Tunisian wheat value chain, FAO sponsored a special survey of farmers in the governorates of Bizerte and Siliana. The survey was based on a random sample from a list of cereal producers in each governorate. The survey covered a sample of 105 farms in Bizerte and 200 farms in Siliana.

The governorate of Bizerte is closer to the capital, Tunis, and has a more modern cereal sector as highlighted by several farm characteristics, shown in Table 3.2. Farmers in the area are typically more educated, and there is more ownership of combine harvesters. Also in Bizerte, a greater share of farmers sell directly to collection centres instead of going through other formal and informal commercial channels. Farms are slightly larger on average in Siliana, but the area of land used for cereal cultivation is much larger in Bizerte. Surprisingly, contrary to what sources indicate, in this particular sample yields are higher in Siliana than in Bizerte. However, the surveyed sample has a larger share of irrigated cereal farms, much larger than what census figures indicate: twelve percent in the sample versus one percent in the census. The distribution of farm sizes, shown in Error! Reference source not found., demonstrates that in Bizerte there is more consolidation of land than at national levels, with a high prevalence of medium-sized farms (8–35 hectares). In contrast, in Siliana there is a much higher prevalence of small cereal farmers, closer to the national distribution of cereal farms, cf. Table 3.1.

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Table 3.2 Wheat farmer characteristics

Variable	Mean Bizerte	Mean Siliana	Mean Total
Losses 2014–2017 (% total production)	4.6	7.3***	6.3
Age of farmer (years)	54.2	57.6**	56.4
Education: illiterate (% operators)	6.5	20.0***	15.3
Education: literate, no formal education (% farmers)	13.1	19.5	17.3
Education: Primary (% farmers)	29.0	26.0	27.0
Education: Secondary (% farmers)	25.2**	13.5	17.6
Education: Higher (% farmers)	26.2	21.0	22.8
Civil status: married (% farmers)	80.0	95.0***	89.5
Diploma agricultural technical training (% farmers)	10.1	17.0*	14.6
Technician diploma in agricultural tech (% farmers)	6.1	11.5*	9.5
Engineer diploma in agricultural tech (% farmer)	3.5	3.0	3.2
Other professional training (% farmers)	7.1	8.5	8.0
Live on the farm (% farmers)	40.0	46.2	44.0
Receive public phytosanitary services (% farms)	17.4	23.0	21.0
Receive public agricultural technical services (% farms)	14.8	27.5***	22.9
Receive public machinery service (% farms)	5.2	7.0	6.3
Use private service advice (% farms)	11.3	26.5***	21.0
Use other private services (% farms)	4.3	5.0	4.8
Total area of the farm (hectares)	183.2	210.9	201.0
Cereal area 2016–17 (hectares)	204.4***	38.2	98.9
Cereal area 2016–17 (% total area)	33.6***	5.8	15.4
Cereal production 2016–17 (tonnes)	54.5	101.0**	84.7
Cereal yield 2016–17 (quintal/hectare)	38.0	65.9***	56.3
Irrigated area 2016–17 (% total area)	2.5	11.6***	8.2
Sale to collection centre (% of production)	86.4***	61.2	70.2
Sale to intermediaries (% of production)	5.2	6.7	6.2
Sales direct to farmers (% of production)	0.0	6.0***	3.9
Use for seed (% production)	2.1	3.7*	3.1
Rent a combine harvester (% farms)	76.4	89.5***	84.8
Ask for device setting (% farms)	70.4	65.0	67.0
Looking to rent a high-performance combine (% farms)	68.7	66.0	67.0
Looking to rent a combine in good condition (% farms)	68.7	74.5	72.4
Easily find a combine to rent (% farms)	48.7	50.5	49.8
Own the combine harvester (% farms)	30.3***	16.5	21.4
Set own machine for harvest (% farms)	27.0**	15.5	19.7
Machine setting revised between two harvests (% farms)	26.1**	15.5	19.4

Variable	Mean Bizerte	Mean Siliana	Mean Total
Easily find spare parts for the machine (% farms)	16.5	11.5	13.3
Store grain on-site before delivery (% farms)	28.7	33.7	32.0
Store grain in bulk (% farms)	6.1	2.5	3.8
Store grain in bag (% farms)	18.3	31.0***	26.3
Store grain in suitable space (% farms)	19.1	18.5	18.7
Type of transport: own (% farms)	34.8**	22.0	26.7
Type of transport: company (% farms)	21.7	24.5	23.5
Type of transport: harvester owner (% farms)	18.3	28.5**	24.8
Distance to the nearest collection centre (km)	11.8	13.1	12.7
Private collection centre (% farms)	63.5	90.5***	80.6
Quantity control by electronic scale in collection centre (% farms)	84.3	88.0	86.7
Quality control in collection centre (% farms)	98.1	98.5	98.3

Source Authors' calculations based on: **FAO.** 2020c. *Analyse des pertes alimentaires: causes et solutions (Étude de cas de la chaîne de valeur céréalière en Tunisie).* Tunis.

Notes: Asterisks indicate that the observed mean is larger in the marked governorate. *** indicates that the difference is statistically significant at the 99% confidence level, or ** 95%, or * 90%.

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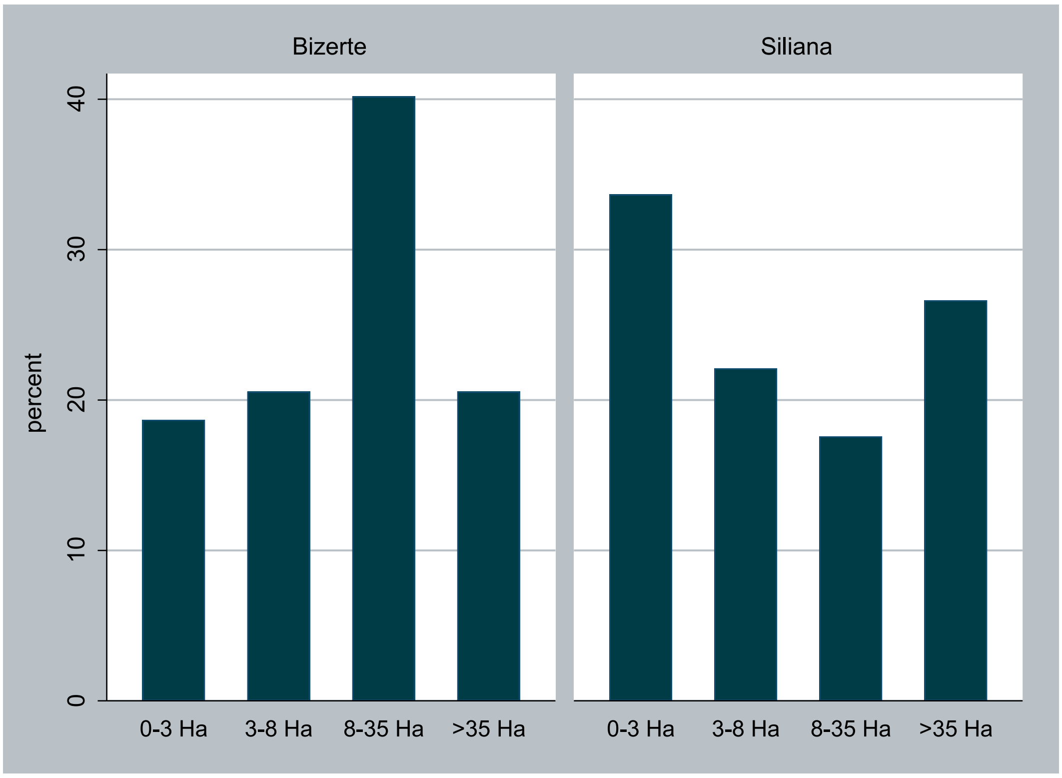
Figure 3.2 Wheat farm size distribution by governorate



Source: Authors' calculations based on: **FAO**. 2020c. *Analyse des pertes alimentaires: causes et solutions (Étude de cas de la chaîne de valeur céréalière en Tunisie)*. Tunis.

The focus of this study is on cereal losses. Surveyed farmers were asked what percentage of wheat they lose, based on their perception and understanding, not independently measured losses. As shown in Table 3.2, perceived cereal losses are significantly higher in Siliana (7.3 percent) than in Bizerte where farmers estimate losses at 4.6 percent. Given that the focus of losses is at the farmer node, within a much wider cereal value chain, there are limited areas where losses can occur. The first activity, a critical one for all farmers, is harvesting; the next is storage, if farmers do indeed store (and most of them store for a short term before sending to collection centres, or selling at the farm gate); and finally there are losses during transportation to the point of sale (mostly collection centres), but this is perceived by the farmer only if the sale transaction is recorded at the buyer's location (i.e. collection centre) instead of at the farm gate. This discussion highlights that for farmers, perceived losses are mostly determined by harvesting practices, and the anecdotal evidence from the field as well as the simple descriptive analysis suggests that a key determinant of losses is access to an adequate combine harvester (moissonneuse bateuse), and the correct use of this machine.

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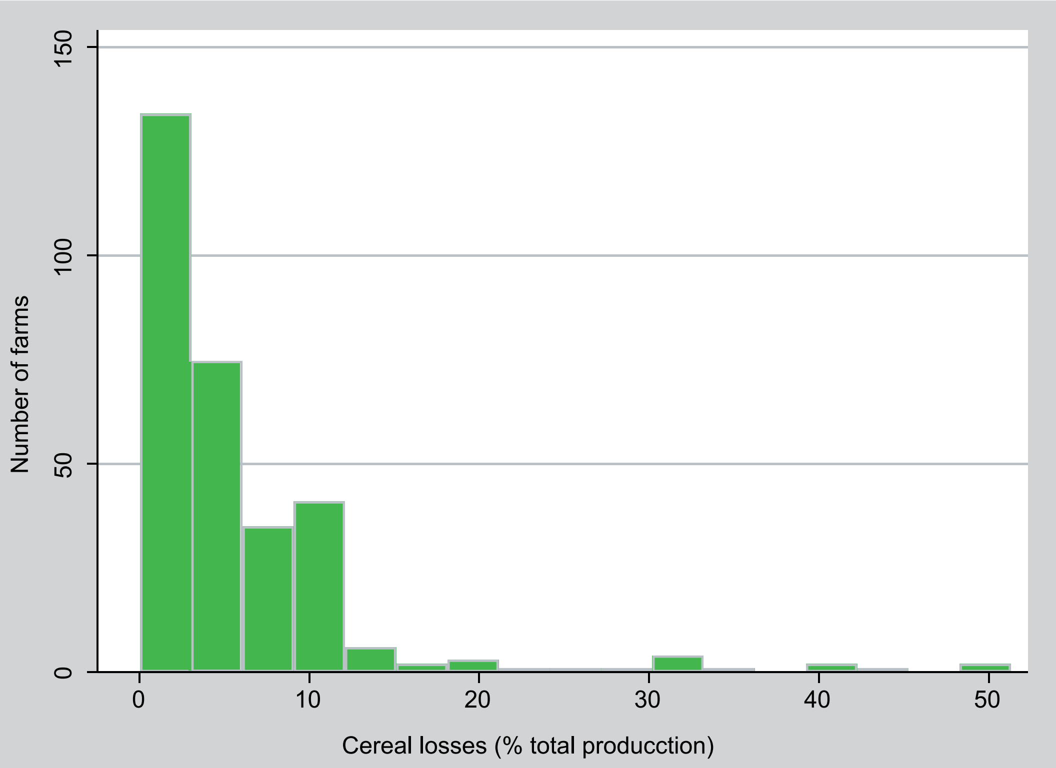
Figure 3.3 Distribution of wheat losses by share lost



Source: Authors' calculations based on: **FAO**. 2020c. *Analyse des pertes alimentaires: causes et solutions (Étude de cas de la chaîne de valeur céréalière en Tunisie)*. Tunis.

Figure 3.3 shows that most farmers report losses in the zero to fifteen percent range, consistent with harvesting loss rates, but a few farmers report catastrophic losses of up to 50 percent of production, losses most likely to have happened prior to harvest. Figure 3.4 shows that larger farmers have on average lower loss rates in both governorates. This is an expected result, because any field-level loss, like losses while harvesting corners, are distributed over a larger area for larger farmers, and proportionally any field-level loss will be higher for smaller farms. In Bizerte smaller farms display larger losses than medium-sized farms, but in Siliana small farmers display losses comparable to medium-sized farms.

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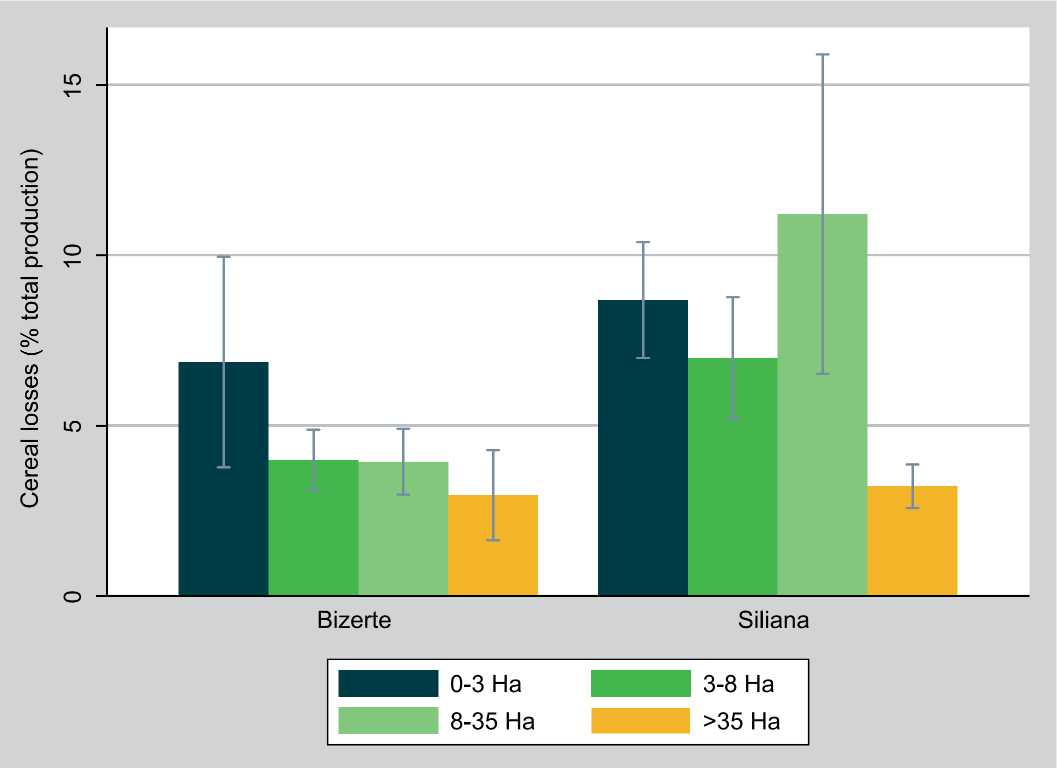
Figure 3.4 Distribution of losses by governorate and farm size



Source: Authors' calculations based on: **FAO**. 2020c. *Analyse des pertes alimentaires: causes et solutions (Étude de cas de la chaîne de valeur céréalière en Tunisie)*. Tunis.

To determine the farm characteristics that have the greatest impact on losses, the LASSO (least absolute shrinkage and selection operator) algorithm (Tibshirani, 1991) is used to sort possible explanatory variables by their partial correlation ranking, for inclusion in a regression model that explains perceived losses (see Table 3.3). The regression in the first column clearly shows that the characteristic with the highest marginal impact is setting (adjusting and calibrating) the combine harvester before each use. This confirms, through a multivariate analysis, what users on the field perceived: the most important contributor to reducing losses is adjusting the machine to field conditions. (An available indicator of harvester ownership was not included in this analysis because almost all owners "set the machine" although not all who adjust the machine are owners). Controlling for all other observable characteristics, the action of adjusting the harvester to field conditions alone reduces losses by 2.6 percentage points, or, roughly, about 50 percent of the mean perceived losses. Farmers who own a combine harvester set the machine prior to use, and those who do not own a machine do not adjust it (with only three exceptions). The other important characteristic that reduces losses is human capital, measured by farmers having a technical diploma in agricultural technology.

Table 3.3 Regression of cereal losses at farm level (percentage of total production) on farm characteristics

	OLS1	OLS2	Weighted GLS1	Weighted GLS2
Set the machine before harvest (dummy)	-2.623* (1.510)	-2.099 (1.989)	-2.073*** (0.545)	-3.064*** (0.756)
Sale at the collection centre (% of production)	-0.066*** (0.025)	-0.066*** (0.025)	-0.017** (0.008)	-0.020** (0.008)
Log of cereal area 2016–17 (hectares)	1.004 (1.977)	1.036 (2.011)	-1.222** (0.522)	-1.506*** (0.575)
Set the machine*log cereal land		-0.131 (0.428)		0.289** (0.135)
Log distance to the nearest collection centre (km)	0.612 (0.491)	0.612 (0.490)	0.072 (0.121)	0.021 (0.125)
Siliana (dummy)	0.161 (1.627)	0.205 (1.632)	1.127* (0.592)	1.096* (0.625)
Technician diploma in agricultural tech (dummy)	-2.783*** (0.767)	-2.794*** (0.780)	-1.374*** (0.240)	-1.391*** (0.251)
Private services advice (dummy)	1.048 (1.013)	1.109 (1.044)	1.677*** (0.408)	1.239*** (0.447)
Easily find the spare parts of the machine (dummy)	-0.553* (0.290)	-0.572* (0.325)	-0.098 (0.074)	-0.035 (0.083)
Purchase and sale at farm level (dummy)	-0.062** (0.025)	-0.062** (0.025)	-0.002 (0.009)	0 (0.009)
Rent a combine harvester (% farms)	-0.526 (1.523)	-0.539 (1.540)	-1.330*** (0.411)	-1.339*** (0.407)
Log cereal land*transportation and harvest by same provider	-1.46 (0.910)	-1.487 (0.915)	-0.801** (0.331)	-0.717** (0.356)
Sale to intermediaries (% of production)	-0.019*** (0.006)	-0.019*** (0.006)	-0.015*** (0.002)	-0.014*** (0.002)
Looking to rent a high-performance combine (dummy)	-0.054** (0.021)	-0.054** (0.021)	-0.013 (0.008)	-0.013 (0.008)
Store grain in bag (dummy)	-0.643 (1.930)	-0.653 (1.932)	0.906* (0.523)	1.135** (0.565)
Log cereal land*irrigated area 2016–17 (%)	3.371** (1.400)	3.334** (1.377)	0.459 (0.587)	0.504 (0.567)
Log cereal land*sale direct to farmers	0.591 (1.579)	0.611 (1.591)	-0.358 (0.574)	-0.639 (0.586)
Log cereal land*quality control in collection centre	0.506 (2.048)	0.537 (2.049)	1.307** (0.577)	1.104* (0.588)
Log cereal land*purchase and sale at farm level	-2.873*** (0.909)	-2.900*** (0.940)	-1.659*** (0.306)	-1.448*** (0.326)
Siliana*diploma agricultural technical Training	-0.262 (2.355)	-0.375 (2.224)	-1.772** (0.735)	-1.458* (0.766)
Siliana*private operation	-0.105 (1.863)	0.06 (2.060)	1.043* (0.565)	0.705 (0.605)

	OLS1	OLS2	Weighted GLS1	Weighted GLS2
Siliana*store grain in bag	-0.261 (0.759)	-0.218 (0.702)	0.247 (0.176)	0.131 (0.186)
Siliana*rent a combine harvester	1.259 (1.261)	1.207 (1.253)	-0.076 (0.518)	0.051 (0.523)
Constant	10.613*** (2.751)	10.424*** (2.976)	8.104*** (0.887)	8.963*** (0.940)
Average marginal effects				
Set the machine for your harvest (Dummy)	-2.623* (1.510)	-2.437 (1.488)	-2.073*** (0.545)	-2.321*** (0.590)
Log of cereal area 2016–17 (hectares)	-0.180 (1.199)	-0.219 (1.133)	-1.051*** 0.267	-0.950*** (0.276)
Adjusted R^2	0.19	0.19		
AIC	2006.26	2008.22		
BIC	2091.53	2097.19		
p-value, Regression F-stat	0.00	0.00	0.00	0.00
Obs.	301	301	301	301

Source: Authors' calculations based on: **FAO**. 2020c. *Analyse des pertes alimentaires: causes et solutions (Étude de cas de la chaîne de valeur céréalière en Tunisie)*. Tunis.

Notes: Standard errors in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$. OLS columns use White's heteroscedastic consistent variance matrix. Weighted GLS regressions use the inverse of the standard error as weighing factors.

The variability of the loss rates differs according to the characteristics of the farmers. The source of this heteroscedasticity is due to the large range of farm scales. This heteroscedasticity is addressed by using White's method for estimating consistent standard errors in the first two columns of Table 3.3. In a small sample, however, heteroscedasticity can bias results, not only standard errors. Therefore, a preferred approach is the GLS method, where observations are weighted by the inverse of the individual predicted variance, both a type of GLS estimator and a Weighted Least Squares estimator. Columns 3 and 4 in Table 3.3 show these estimations where the difference between columns is a term to account for a possible interaction effect between setting the combine harvester and farm size in column 4. Note that these estimations show that, all else equal, larger farms have lower losses. In other words, in addition to owning and setting the combine harvester, larger farms have lower losses driven by scale. This is an important result, because it means that, as shown in Foster and Anriquez (2019), increases in farmers' prices will be associated with a reduction in losses.

Table 3.4, using the regression results of column 4 in Table 3.3, shows an important result of this study. The table demonstrates that the gains from setting the machine decrease with size. In other words, setting the machine has a larger relative impact in reducing losses in the case of smaller farms. For smaller farms, setting the machine can reduce losses by almost three percentage points, while for large farms this gain is not measurable, because most own and do setup the combine harvester before each use.

Table 3.4 Marginal effects of setting the combine harvester before harvest, by land size

Cereal land (hectares)	Cereal losses with and without setting the Combine Harvester (%)			
	No	Yes	Difference	Difference *p*-value
0–3	9.4	6.4	-2.9	0.00
3–8	7.4	4.8	-2.6	0.00
8–35	5.3	3.1	-2.2	0.00
>35	0.04	0.0	-0.04	n/a

Source: Authors' calculations based on: **FAO**. 2020c. *Analyse des pertes alimentaires: causes et solutions (Étude de cas de la chaîne de valeur céréalière en Tunisie)*. Tunis.

Table 3.5 introduces the economics of the decision to reduce field harvesting losses. One observes that in Bizerte the gains from setting the machine in terms of USD/hectare is similar across farm sizes at USD 7.5–8.5/hectare. In Siliana, on the other hand, the gains of setting the machine is larger for smaller farms at USD 2.6/hectare, but much smaller than in Bizerte.

Table 3.5 Per-hectare reduction of losses by setting the combine harvester, in USD, by farm size

Region	0–3 (Ha)	3–8 (Ha)	8–35 (Ha)	>35 (Ha)	Total
Bizerte	7.8	8.6	8.5	7.2	8.1
Siliana	2.6	1.4	0.7	0.5	1.4
Total	3.7	3.8	5.0	2.4	3.8

Source: Authors' calculations based on: **FAO**. 2020b. *Analyse des pertes alimentaires: causes et solutions (Étude de cas de la chaîne de valeur céréalière en Tunisie)*. Tunis.

Table 3.6 provides more insight into the economic analysis, showing that, for small firms, setting the machine results in minimal monetary gains – only USD 5 in Siliana, and USD 16 in Bizerte. If the cost of calibrating the machine, i.e. by hiring a more prepared operator or by renting a more adaptable machine, is greater than USD 5 in Siliana, the rational behaviour for a small farmer is simply not to pay for this additional feature. Conversely, the monetary gains for large farmers are economically significant, which makes it highly unlikely that they would not spend additional resources in adequately calibrating the harvester to their fields' conditions.

Table 3.6 Average total reduction of losses by setting the harvester, in USD, by farm size

Region	0–3 (Ha)	3–8 (Ha)	8–35 (Ha)	>35 (Ha)	Total
Bizerte	15.6	47.6	127.5	1,451.2	368.9
Siliana	5.2	7.3	9.5	159.4	47.5
Total	7.4	20.7	74.6	538.3	158.5

Source: Authors' calculations based on: **FAO**. 2020b. *Analyse des pertes alimentaires: causes et solutions (Étude de cas de la chaîne de valeur céréalière en Tunisie)*. Tunis. Based on a farm gate price of USD 150/tonne.

At this point the reader will note that a clear way of reducing percentage losses in the context of Tunisian cereal production would be to promote farm consolidation. There is, however, room for reducing losses among small wheat farmers in Tunisia, although it would require collective action to overcome the economic barriers imposed by small scale. For example, neighbouring small farmers could organize to join small plots into larger plots to exploit economies of scale. Another example of collective action would be to organize into cooperatives to promote access to, and better use of, improved harvesting machinery.

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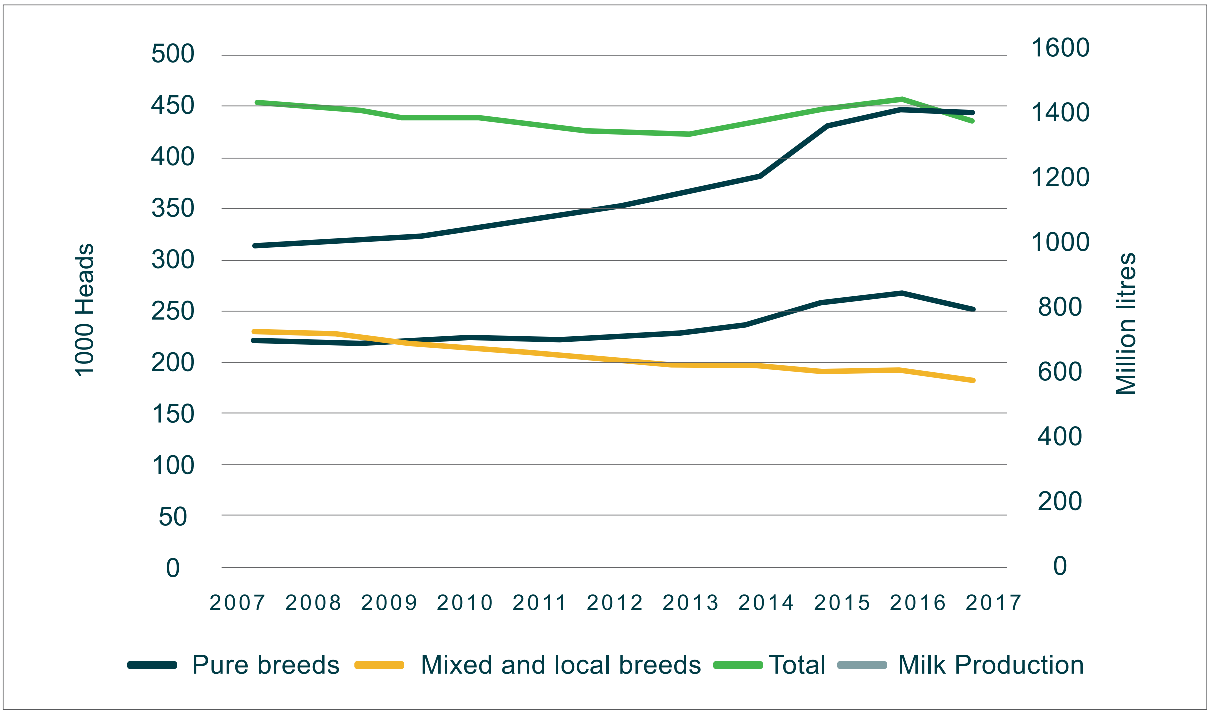
Losses in Tunisian dairy production

Milk Production in Tunisia

Tunisia produces around 1.3 million litres of fresh cow milk each year. Milk production has increased in recent years, mainly due to improvements in the genetic composition of the dairy herd, rather than to an increase in the total number of cows. As Figure 3.5 shows, the stock of pure breed cows has grown steadily since 2007, while the stock of mixed race cows has fallen, maintaining a relatively stable stock of approximately 450 thousand cows, but with growing total milk supply.

Figure 3.5 **Female bovine heads and milk production, 2007–2017**



Source: GIVLait, cited in: **FAO**. 2021c. Analyse des pertes alimentaires: causes et solutions — *Étude de cas de la chaîne de valeur du lait en Tunisie*. Tunis. (also available at https://www.fao.org/documents/card/en/c/ca7334fr/).

As shown in Table 3.7, most Tunisian dairy farms are relatively small. Of the 110 000 farms with lactating cows, nearly three-quarters of them have fewer than four cows. Farms with more than ten cows number about 10 000. In an industry characterized by important economies of scale, a high prevalence of small farms is observed in Tunisia, versus comparable milk industries in other middle-income countries. The agricultural census of 2005 estimated the number of cows in Tunisia at 441 000. With 78 000 heads, Bizerte is one of the main milk producing governorates in the country; Mahdia, with almost 34 000 heads is a medium-sized milk producing governorate (see Figure 3.6).

Table 3.7 Cattle farms by number of female bovine heads

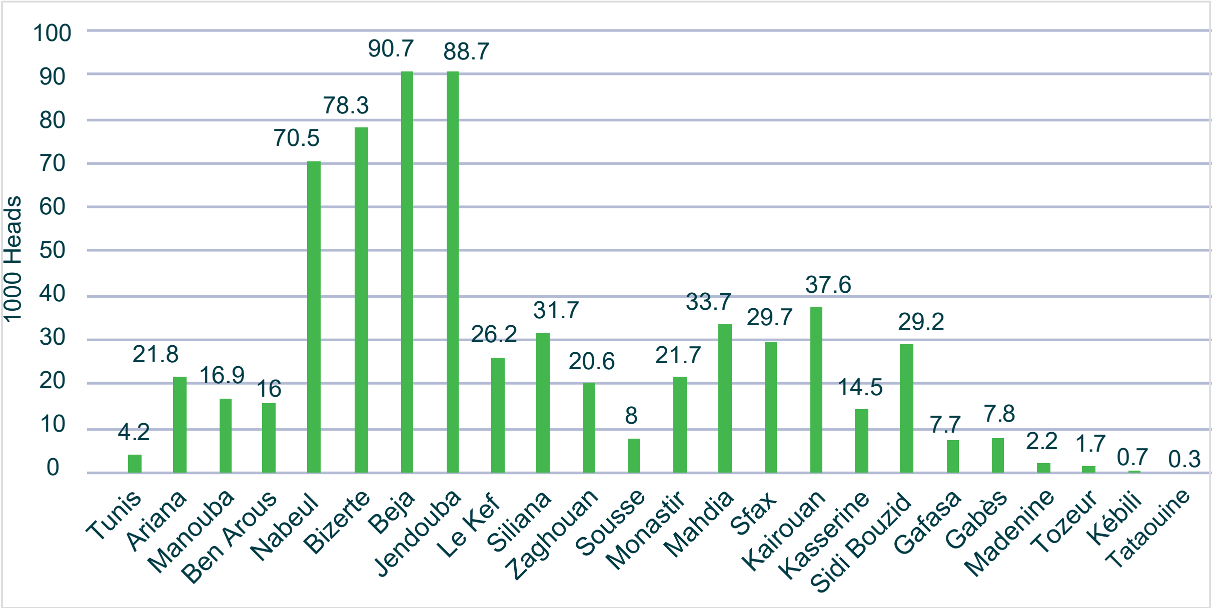
Number of Female Heads	Farms
0	1 680
1–3	75 488
4–5	15 568
6–10	12 208
11–20	5 376
21–50	1 456
51–100	112
100+	112
Total	112 000

Source:

Ministère de l'Agriculture et des Ressources Hydrauliques. 2006. *Enquête sur les Structures des Exploitations Agricoles 2004-2005. Tunis.*

To understand the determinants of losses in milk farms, FAO undertook a specialized study of the milk industry in Tunisia (Khaldi, 2017). As part of this study, a survey was conducted on a sample of milk farmers from the Governorates of Mahdia and Bizerte. The survey interviewed 200 milk farmers in Mahdia out of a total population of nearly 6 000 farmers. In Bizerte, 200 farmers were also surveyed from total a population of nearly 11 000.

Figure 3.6 Stock of bovine cattle by governorate



Source: Ministère de l'Agriculture et des Ressources Hydrauliques. 2006. *Enquête sur les Structures des Exploitations Agricoles 2004-2005.* Tunis.

As Table 3.8 shows, there are significant differences between milk farms in the two regions of Bizerte and Mahdia. Percentage losses are notably higher in Bizerte than in Mahdia (1.1 percent compared to 0.4 percent) although milk farms are larger in Bizerte than in Mahdia (on average, 13 lactating cows compared to 5). On the other hand, productivity is higher in Mahdia, with a daily output of 19.2 litres/cow, while daily milk output in Bizerte is on average 17 litres/cow. In Bizerte, education levels are higher for both the farm owner and the person in charge of milking relative to Mahdia. Bizerte farms are situated, on average, slightly further away from collection centres, at an average distance of 6.9 km compared to 5.5 km in Mahdia. Mechanized milking appears to be a key characteristic associated with higher productivity on dairy farms, which is also expected to be correlated negatively with loss rates. There are no statistically significant differences between regions in terms of mechanized milking; on average 75 percent of farms use mechanized milking in their operations. There is little use of cold storage on Mahdia (2.5 percent of farms), while in Bizerte 16.3 percent of farms have cold storage on-site. In Mahdia, most milk is collected in aluminium cans (87 percent of container capacity), while in Bizerte there is greater heterogeneity in milk collection methods: plastic, aluminium and stainless steel cans are used, but so too are buckets (comprising 11 percent of total container capacity).

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Table 3.8 Characteristics of milk & dairy farms in Bizerte and Mahdia

Variable	Mean Bizerte	Mean Mahdia	Mean Total
Milk losses (% of total production)	1.18***	0.38	0.78
Daily milk production (litres	231.61***	92.31	161.08
Log of cereal area 2016–17 (hectares)	16.96	19.15***	18.09
Duration of lactation (months)	9.99***	8.03	8.98
Land area (hectares)	35.36***	4.54	19.76
Cattle, total (n)	33.52***	12.64	22.95
Lactating cows (n)	12.79***	4.92	8.81
Female farmers (% farmers)	3.06	7.46**	5.29
Age of farmers (years)	49.58	51.26	50.43
Education of farmers: illiterate (% farmers)	6.19	18.18***	12.24
Education of farmers: literate (% farmers	6.19**	2.02	4.08
Education of farmers: primary (% farmers)	41.75	53.54**	47.70
Education of farmers: secondary (% farmers)	32.47**	23.23	27.81
Education of farmers: higher (% farmers)	13.40***	3.03	8.16
Farmer membership: SMSA (% farmers)	14.29	73.13***	44.08
Farmer membership: GD (% farmers)	15.31***	0.00	7.56
Technical and health monitoring (% farmers)	62.57	75.76 ***	69.35
Female dairypersons	7.14	53.23***	30.48
Age of dairypersons (years)	43.72	44.04	43.88
Family employed at dairy	19.39***	2.49	10.83
Education of dairypersons: illiterate (% dairypersons)	6.74	30.46***	18.72
Education of dairypersons: literate (% dairypersons)	6.74***	0.51	3.59
Education of dairypersons: primary (% dairypersons)	44.04	44.67	44.36
Education of dairypersons: secondary (% dairypersons)	37.31***	22.34	29.74
Education of dairypersons: higher (% dairypersons)	5.18*	2.03	3.59
Trained in livestock monitoring	27.38***	3.55	14.52
Trained in milking techniques	28.03***	10.55	18.26
Access to a quality road (% total distance)	74.70	84.29**	80.02
Distance from nearest collection point (km)	6.87**	5.45	6.10
Time from milking to delivery (hours)	2.06***	0.82	1.43
Access to potable water (% farms)	78.06	85.07*	81.61
Access to well water (% farms)	47.45***	6.97	26.95
Electricity sources: STEG (% farms)	95.92	96.02	95.97
Electricity sources: Generator (% farms)	8.67***	0.50	4.53
Mechanized milking (% farms)	73.47	78.11	75.82
Washing container (% farms)	85.71	88.06	86.90

Variable	Mean Bizerte	Mean Mahdia	Mean Total
Washing udders (% farms)	93.88	98.01**	95.97
Washing cans (% farms)	62.24	97.01***	79.85
Washing tank - individual (% farms)	6.63***	0.50	3.53
Washing tank - collective (% farms)	1.53*	0.00	0.76
Milking inside a barn (% farms)	78.57	82.09	80.35
Hygiene practices in milking location: satisfactory or excellent (% farm)	65.82	65.17	65.49
Frequency of cleaning the milking site (times/week)	6.77***	4.74	5.73
Cold storage in the farm (% farms)	16.26***	3.68	9.09
Capacity of containers per cow (litres)	21.61	22.54	22.09
Uses plastic cans (% total capacity)	7.08***	0.00	3.49
Uses stainless steel cans (% total capacity)	11.76***	2.49	7.07
Uses aluminium cans (% total capacity)	41.91	87.09***	64.78
Uses plastic bucket (% total capacity)	9.56***	2.19	5.83
Uses aluminium bucket (% total capacity)	0.79**	0.07	0.42
Uses stainless steel bucket (% total capacity)	0.52**	0.00	0.25
Uses individual tank in regular or good condition (% farms)	8.67***	1.99	5.29
Uses collective tank (% farms)	1.02	0.00	0.50
Milk transformation (% farms)	3.57	5.47	4.53
Systematic quality control of milk (% farms)	14.80	55.72***	35.52
Sample Size	196.00	201.00	

Source: Authors' calculations based on milking farms survey, 2018.

Notes: Asterisks indicate that the observed mean is larger in the marked governorate. *** indicates that the difference is statistically significant at the 99% confidence level, or ** 95%, or * 90%.

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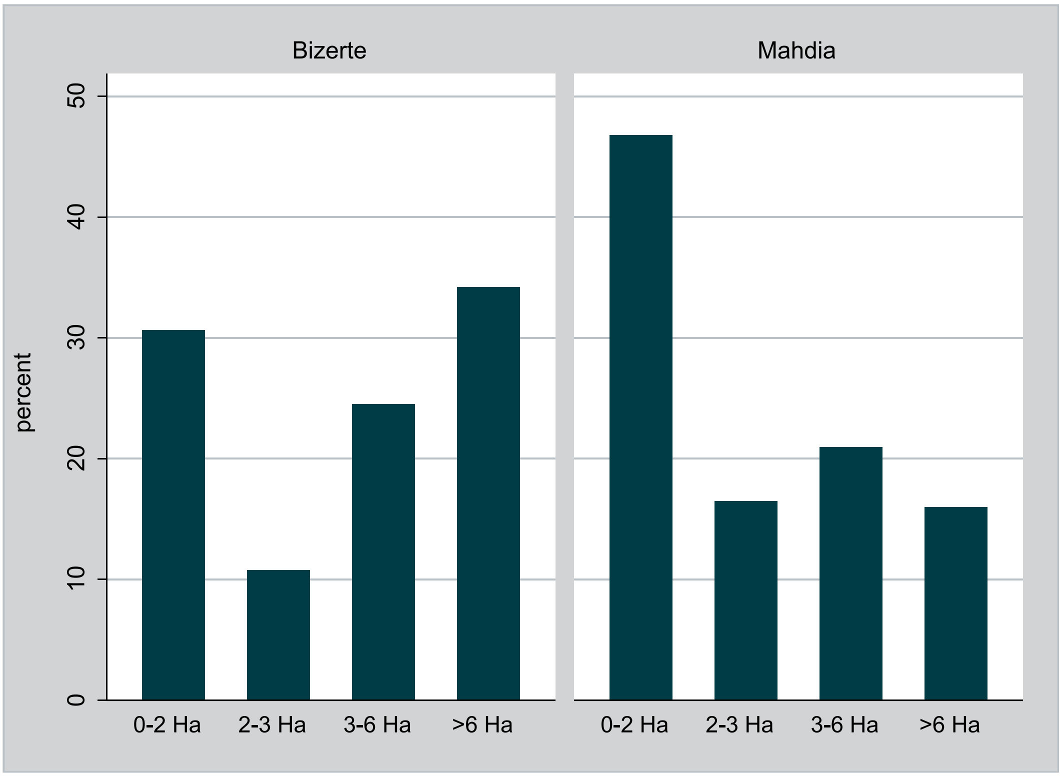
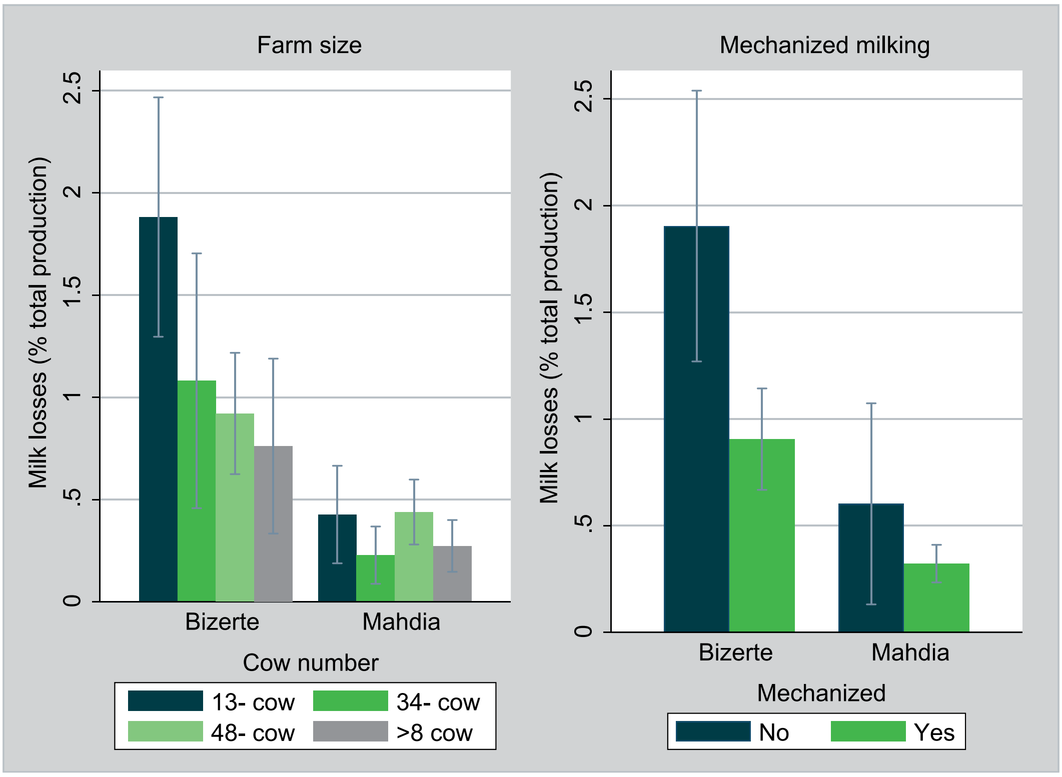
Figure 3.7 Distribution of milking farms by size (number of cows) and governorate



Source: Authors' calculations based on milking farms survey, 2018.

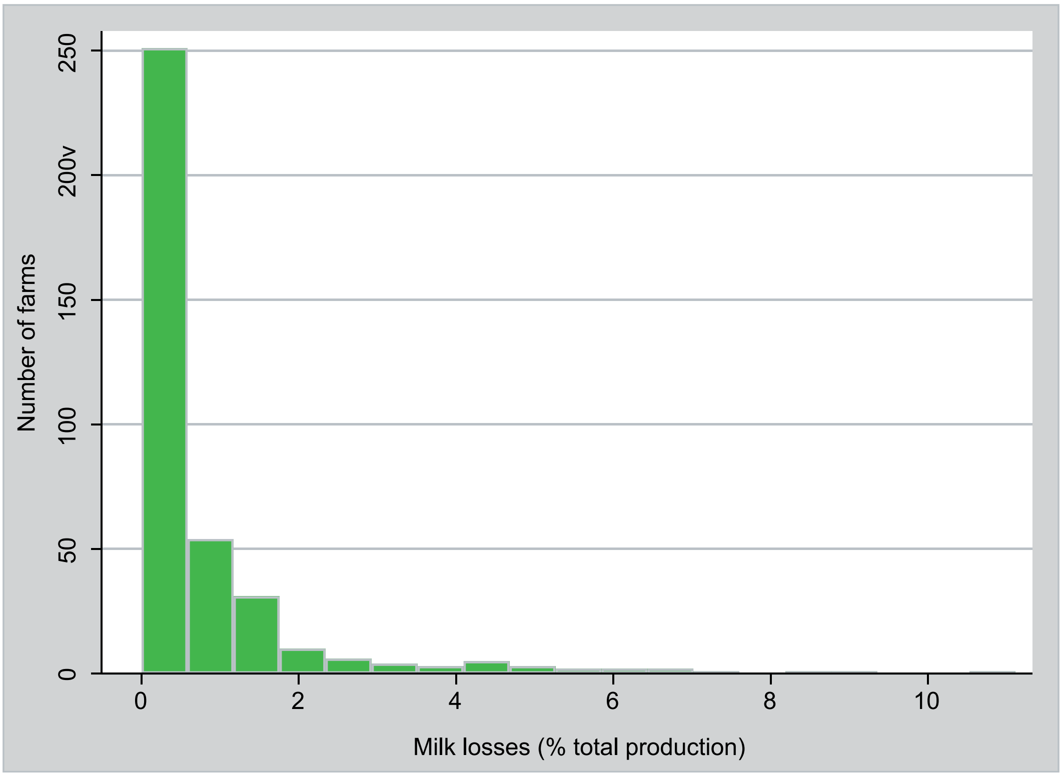
The distribution of farm sizes shown in Figure 3.7 demonstrates that milk farms are notably smaller in Mahdia. Only about ten percent of farms have more than eight milking cows, while in Bizerte 30 percent of farms have more than eight milking cows. As in the case of cereal production, scale economies are important in dairy production; mechanized milking machinery and quality and clean infrastructure, which increase productivity and reduce losses, are aspects of production systems that carry large fixed costs and are more likely to be associated with scale economies. It is therefore notable that, as seen in Figure 3.8, loss rates are lower in Mahdia, where dairy farms are smaller. Furthermore, there is no clear relationship between scale and average losses in Mahdia, although there is such a relationship in Bizerte. As the figure shows, losses in farms with one to three cows in lactation have on average higher losses (2 percent) than dairy farms with eight or more cows (only 0.8 percent). Overall, as stressed above, losses are rather low, and as Figure 3.9 indicates, there is little variability in reported losses. Nearly four out of five dairy farms reported percentage losses below 1.1 percent. This reduced variability in farm-level perceived losses limits the ability of econometric analysis to detect and estimate the correlation of losses with their potential determinants in the case of Tunisian dairy farms.

Figure 3.8 Milk losses in Mahdia and Bizerte, by farm size and presence of mechanized milking



Source: Authors' calculations based on milking farms survey, 2018.

Figure 3.9 Distribution of milk percentage losses among Mahdia and Bizerte milking farms



Source: Authors' calculations based on milking farms survey, 2018.

Determinants of Dairy Farm Milk Losses in Tunisia

Inspection of the data shows that the relationship between losses and various farm characteristics is influenced by the size of the farm operation, and that there is a high degree of variance in the data that appears correlated with the scale of the operation, particularly herd size (i.e., heteroscedasticity). That is, larger farm operations tend to have less variability in their loss rates, all else equal, than smaller operations.[6] One possible statistical approach, therefore, is to estimate a simplified relationship between milk losses and farm characteristics using ordinary least squares, but, when making statistical inferences regarding the determinants of losses, to correct the standard errors of the coefficient estimates (e.g. with White's heteroscedastic-consistent method). These results are reported in the first column of . Another method that deals explicitly with this heteroscedasticity arising from a size-dependent variance of loss rates linked to farm characteristics is to follow a two-stage approach first proposed by Just and Pope (1979). First, estimate a model explaining expected loss rates by standard ordinary least squares, then use the square of each residual as an estimator of individual variances to estimate a model that predicts the log of variance. Then, the predicted variance is used to estimate a generalized least-squares regression, which is equivalent to weighting the original observations by the inverse of the predicted standard error. The GLS approach is the model presented in the second column of . This procedure can be iterated, searching over the parameter space to maximize the likelihood of the sample, if corrected errors are assumed to be normally distributed (Saha *et al.*, 1997). The iterated GLS model is presented in the third column of the table.

Table 3.9 demonstrates that the most robust relationships between losses and farm characteristics are related to scale. Despite the simple correlation between scale and losses being unclear from a simple inspection of the data (see Figure 3.8), after controlling for various farm characteristics the scale effect on losses becomes evident. In the first place, increasing the number of cows significantly reduces losses. Adopting mechanized milking also reduces losses (recall that 75 percent of dairy farms use mechanized milking). Mechanized milking, of course, is associated with increased scales of production and carries with it significant fixed costs. Additionally, the amount of container capacity per cow (another scale indicator) also reduces losses. Surprisingly, the type of container – can (sealable), or bucket – does not affect loss levels. Also, the data does not support the hypothesis that the use of stainless steel containers, which are easier to clean and sanitize, is correlated with statistically significant lower levels of losses.

The other characteristic that reduces loss rates (and is robust to model specification) is the access to quality roads. This result highlights the role of public goods in reducing dairy farm losses, and farm losses more generally. Somewhat surprisingly, the results show that being a member of the Mutual Marketing and Agricultural Services Company (the SMSA) is, ceteris paribus, associated with higher losses; but this result does not likely point to a causal effect, but rather to a selection effect, whereby farmers with lower productivity are drawn into this collective organization.

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[6] One likely reason that there is less variability, ceteris paribus, in operations with more cows relative to those with fewer is that, if losses are due in part to random perturbations associated with each cow, then the loss rates in larger operations would reflect an averaging-out of a greater number those perturbations, which would tend to offset each other.

Table 3.9 Determinants of milk percentage losses among Tunisian dairy farms

	OLS White's Std. Error	Inverse Variance GLS	Inverse Variance ML	
			Losses	Variance
Mechanized milking (dummy)	-0.606**	-0.274***	-0.342**	-0.751***
	(0.268)	(0.068)	(0.152)	(0.129)
Uses can (% total capacity)	0.001	0.001	0.002	-0.001
	(0.003)	(0.001)	(0.002)	(0.003)
Uses bucket (% total capacity)	-0.003	0.001	0.004	-0.007*
	(0.005)	(0.002)	(0.003)	(0.004)
Log of the number of lactating cows (n)	-0.291***	-0.086***	-0.162*** -	-0.188**
	(0.098)	(0.022)	(0.040)	(0.095)
Log capacity of containers per cow (litres)	-0.186*	-0.086***	-0.141***	-0.138*
	(0.112)	(0.023)	(0.046)	(0.080)
Access to quality road (% total distance)	-0.006**	-0.006***	-0.004***	-0.009***
	(0.002)	(0.001)	(0.001)	(0.001)
Region Bizerte (dummy)	0.096	0.666***	-0.127	0.393
	(0.744)	(0.161)	(0.419)	(0.377)
Time: milking to delivery (hrs)	0.008	-0.003	0.005	-0.054***
	(0.007)	(0.003)	(0.003)	(0.014)
Female dairyperson [milker] (dummy)	0.13	-0.032	-0.039	-0.028
	(0.156)	(0.030)	(0.067)	(0.119)
Education of dairyperson: literate (dummy)	-0.623*	-0.377***	-0.327**	-0.999***
	(0.331)	(0.056)	(0.130)	(0.219)
Age of dairyperson (years)	-0.006	0.004***	-0.003	0
	(0.005)	(0.001)	(0.003)	(0.004)
Farmer membership: SMSA (dummy)	0.294*	0.137***	0.172**	0.457***
	(0.150)	(0.033)	(0.071)	(0.116)
Washing container (dummy)	0.463	0.227**	0.288	-0.352*
	(0.381)	(0.111)	(0.282)	(0.213)
Bizerte*age dairyperson	0.017	-0.001	0.024***	-0.006
	(0.017)	(0.002)	(0.005)	(0.005)
Bizerte*washing container (dummy)	0.231	0.064	-0.235	1.091***
	(0.436)	(0.134)	(0.316)	(0.312)
Cold Storage on site (dummy)	-0.248	-0.149**	-0.155	-0.403*
	(0.173)	(0.063)	(0.110)	(0.219)
Constant	1.841***	0.827***	1.246***	1.506***
	(0.692)	(0.167)	(0.392)	(0.341)
Adjusted R^2	0.170			
AIC	1255.65		936.29	
BIC	1321.950		1068.880	
p-value, Regression F-stat	0.000	0.000	0.000	
Obs.	365	365	365	

Source: Authors' calculations based on milking farms survey, 2018.

In addition to determining expected losses, the model presented in the third column of also estimates the relationship between the variance of loss rates and farm characteristics. These estimates can be interpreted as showing the manner by which the vulnerability to dairy losses varies across types of dairy farmers. Notably, this model shows that the variability of losses is reduced using mechanized milking, the number of lactating cows, and on-farm cold storage; all scale-related variables. Interestingly, membership in the SMSA is associated with higher variability of milk losses, suggesting perhaps that this group contains a heterogeneous mix of farmers.

The strong effect of scale in reducing losses is a robust and significant result, indicating that if prices received by farmers increase, loss rates will decrease. Therefore, any price distortion that reduces prices at the farm gate would have perhaps unintended but nevertheless negative effects on losses. Also, the results related to scale economies may be interpreted from two different perspectives. On one hand, a way to reduce losses would be to promote farm consolidation. Loss rates, however, appear, on average to be already low; so even small farms could operate with levels of losses that would be considered reasonable from an economic point of view. Furthermore, the result that there are many farmers with a higher propensity for losses associated with the SMSA suggests the possibility of using that organization as an entry point to improve procedures and increase the capital of small farmers, as well as a means of improving overall efficiency of dairy farms in Tunisia.

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Loss reduction using plastic crates in Egyptian tomatoes, from farm to wholesale

This section presents an analysis of the introduction of plastic crates to replace traditional palm crates in Egyptian tomatoes and is based on the information and analyses found in Anríquez ***et al***. (2018) and Anríquez ***et al***. (2020). The main question regards the economic benefit of reducing tomato losses at the farm and wholesale levels by the adoption of plastic crates. The technological change represented by the adoption of plastic crates delivers benefits in the form of reduced losses but comes at a higher cost to using traditional technology.

Tomatoes are an important cash crop in Egypt, which ranks among the five largest tomato producers in the world, producing in the order of eight million tonnes each year. Tomatoes also represent a growing export crop. The value of exports has risen from USD 6 million in 2010 to USD 66 million in 2016.[7] Production occurs year-round, mostly by small-scale, traditional farmers (0.5 to 1.5 hectares) growing 30–40 tonnes/hectare. Fresh tomatoes are highly perishable and, due to the significance of the crop for traditional family farms and to large observed losses, estimates of loss are as high as one third of the crop. As such, local agrifood system analysts have devoted resources to studying harvest and post-harvest tomato losses (FAO, 2018b).

A study of tomato losses between harvest and wholesale related to the use of packing and transport crates was conducted in the Egyptian Governorate of Sharqia and district of Nubaria, the two areas with the highest tomato production.[8] Traditionally, crates made from palm stems following traditional artisanal methods are filled at harvest with, on average, 18 kg of tomatoes, and are used to move tomatoes to market (although in practice, crates are overloaded, oftentimes carrying 20–22 kg). Their useful life is approximately one year. Plastic, stackable crates are a potentially loss-reducing technology popular in other tomato-producing countries. The study sought to evaluate the loss reduction associated with two different types of plastic boxes: a small, relatively inexpensive and disposable plastic crate used to transport 10 kilograms of tomatoes, and a larger, more expensive but sturdier and reusable plastic crate (with an estimated life-cycle of more than two years), capable of carrying approximately 20 kg of tomatoes.

To evaluate the three different containers, four farms in Sharqia were chosen for an experimental measurement of tomato quality losses in the field. Produce from two different areas would be sent to different wholesale markets; each farm received 1 000 disposable plastic crates and 100 reusable plastic crates, with the traditional palm crates provided by the wholesalers (per usual practice). A random sample of five crates of each of the three technologies was observed at the farm before being loaded into open air pick-up trucks that carry up to two tonnes (the standard transport method), and again upon arrival at the wholesale market. Tomatoes in Egypt are not usually stored for many days at the farm or wholesale level, but the study sought to follow the

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[7] Data downloaded from http://www.fao.org/faostat/en/#data/QC, on June 30, 2019.

[8] In Sharqia, the total cultivated area producing vegetables is estimated at about 29,000 hectares, or 11 percent of the total Egyptian tomato cultivation area, producing approximately 12.7 percent of the annual total production capacity (1.5 million tonnes). Nubaria district accounts for 21 percent of the country's total tomato production area (FAO, 2021b).

deterioration of quality and loss rates for six days to ascertain whether the plastic packing crates might delay decay or improve shelf-life.[9]

A first question is, why should one expect lower losses with plastic containers, relative to palm crates? One advantage of plastic crates is that they are uniformly sized, assuring closer and stable stacking, reducing storage space and simplifying truck-loading. Plastic crates also reduce damage during handling and transport, especially that associated with stacking. These advantages relative to traditional palm crates are less pronounced in the case of the disposable plastic boxes, given their less sturdy design. Once the crates are stored there are no differences in additional causes of damage, although the lower rates of damage already sustained after the handling and transport translate into longer tomato shelf life, and therefore into reduced losses over time.

Not all mechanical damage should be visually obvious, but even unobservable mechanical damage should translate into decreased shelf life. Therefore, if there are differences in product shelf life according to the packaging method, as time passes from the moment of transport, these differences and observed losses should become more evident. As a first approach to observed losses, a simple regression analysis examines losses (and the other measured attributes) on day one at the farm and before transport, and at day six at the wholesale market (final observation), controlling for the trial (i.e., the farm of origin). There are 24 observations, three package types x four farms/trials x two days (day one at farm and day six at wholesale market). Columns 1, 3, 5 and 7 of Table 3.10 show the results of these simple regressions for the four measures: quantity loss, quality loss, firmness, and TSS. There is evidence of improved duration and quality of the tomato fruit with the use of plastic cases. In particular, column 3 shows that large plastic cases reduce losses by 30 percent compared to palm crates, and this difference is statistically significant with a 99 percent confidence level. Also, column 5 shows that large plastic boxes increase fruit firmness by 22 percent (the dependent variable is in logarithms and the estimated coefficient is 0.22) compared to traditional boxes, but it is estimated with less precision, differing from zero only with a 90 percent confidence level.

One can note, however, that the baseline levels differ by container type. The initial quality of fruit was higher in the case of the improved (large) plastic containers across farms. Controlling for the initial quality of fruit before leaving the farm (which is the case for the four measures in columns 2, 4, 6 and 8), one observes no measurable improvement associated with plastic containers. All indicators, nonetheless, point in the expected direction, i.e. quantity and quality losses are lower for plastic containers, while firmness is higher and total soluble solids (TSS) are lower (less mature fruit), after controlling for the initial baseline levels, although none of these differences are statistically significant.

These results highlight that, when offered the choice of a new technology that might improve productivity, value chain actors are unlikely to ignore this information. If the limited number of plastic boxes a wholesaler receives (without additional cost) are perceived as better at preserving quality, they have an incentive to sort higher-quality (higher-priced) fruit into those containers so that the higher quality fruit is more likely to arrive at the wholesale market and earn a higher price. A kilogram of blemished or damaged fruit occupies the same space and has the same transport costs as a kilogram of unblemished and undamaged fruit, and so a type of Alchian-Allen selection

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[9] Random samples of each type of crate were taken at the wholesalers for each of six days, measuring fruit quality while stored under normal wholesale market conditions. At each sampling point, the following fruit characteristics where recorded: quantity losses as a percent of weight of unmarketable fruits, quality losses as a percent of weight of fruits showing physical defects, the total soluble solids (TSS) in Brix degrees, and fruit pulp firmness (FPF) in g/cm2, determined using a push-pull dynamometer.

effect[10] would be almost certainly taking place at the farm level. In fact, these first regressions confirm that better fruit is available in plastic containers, but this difference is due to better fruit initially available in plastic containers at the farm sorting stage, before transportation.

Given the expected advantages in transport of sturdier plastic crates relative to palm crates, the analysis turns to the daily examination of losses following initial packing at the farm. This also has the advantage of increasing the number of observations in the regressions. The full sample contains 84 observations: three container types x four farms x seven observations over days (six days, with two observations on the first day before and after transportation). In these regression models, the initial level of the attributes for each container type is controlled for, because the initial quality of the fruit is correlated with container type. Also controlled for are effects associated with specific farms and wholesale markets of destination.[11] The marginal effect of the container type on tomato fruit attributes is not evident from the regression coefficients, because the container type dummies are interacted with the day of the observation sampling. Thus, presented in Table 3.11 is a test of the marginal impact of each container type with respect to the two other containers on each fruit attribute.

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[10] In the case of a basic product where there are quality differences, say a high and low quality, that yield different prices and effectively result in different goods distinguishable by consumers, when one applies a per-unit cost (e.g., transport charge or, in this case, the opportunity cost of the use of a crate), incentives push sellers toward supplying and buyers toward demanding the higher-quality product. The added per-unit costs decrease the relative price of the higher quality good. See, for example, Borcherding, and Silberberg (1978).

[11] These farm and destination effects are represented by dummies for 'trial'. Additional dummy variables control for each day after harvest that the measurement is taken, and for the interaction between the day of measurement and container type.

Table 3.10 Comparing day 6 at wholesale market versus day 1 at farm before transportation

VARIABLES	(1) Quantity loss	(2) Quantity loss	(3) Quality loss	(4) Quality loss	(5) ln (Firmness)	(6) ln (Firmness)	(7) TSS	(8) TSS
Package type (base=Palm crates) Small plastic boxes	-0.367 (0.695)	-0.430 (0.729)	-8.808 (9.024)	-4.571 (8.236)	0.151 (0.119)	0.151 (0.121)	-0.021 (0.190)	-0.080 (0.236)
Large plastic boxes	-0.855 (0.695)	-1.215 (1.149)	-31.180*** (9.024)	-6.943 (12.976)	0.219* (0.119)	0.182 (0.152)	-0.030 (0.190)	-0.080 (0.224)
Trial (base=trial 1)								
Trial 2	-0.071 (0.803)	-0.215 (0.898)	-10.811 (10.420)	-1.112 (10.141)	-0.469*** (0.137)	-0.299 (0.440)	0.434* (0.219)	0.057 (0.882)
Trial 3	0.194 (0.803)	-0.041 (1.010)	-20.197* (10.420)	-4.414 (11.411)	-0.156 (0.137)	-0.082 (0.228)	-0.358 (0.219)	-0.030 (0.774)
Trial 4	-0.077 (0.803)	-0.279 (0.966)	-20.397* (10.420)	-6.747 (10.914)	-0.215 (0.137)	-0.119 (0.275)	0.409* (0.219)	0.115 (0.702)
Dependent variable at farm in day 1 (base line)		-0.015 (0.037)		1.003** (0.422)		0.486 (1.192)		0.828 (1.875)
Constant	1.525** (0.695)	2.216 (1.871)	65.085*** (9.024)	18.581 (21.130)	6.519*** (0.119)	3.235 (8.059)	3.966*** (0.190)	0.983 (6.757)
Observations	24	24	24	24	24	24	24	24
R-squared	0.085	0.094	0.498	0.623	0.467	0.472	0.497	0.502
R²-adj	-0.169	-0.226	0.359	0.491	0.319	0.285	0.357	0.327

Source: Authors' calculations based on data from the 'Tomato 'Load Tracking and Sampling Assessment' carried out by FAO in Egypt, December 2018 to January 2019.

Note: 1) Standard errors in parentheses. *** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1; 2) in the case of quantity losses the quality losses are used as base line, because losses at loading are zero.

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The results are robust; plastic containers do in fact improve fruit attributes, and both quantity and quality losses are statistically lower for both plastic containers as compared to traditional palm crates. Also, fruit transported in plastic crates is firmer, with less TSS (i.e. plastic crate tomatoes are less mature than the fruit transported in traditional crates), and all of these differences are statistically significant with p-values below the one-percent level.

Table 3.11 Marginal effect of package type compared to other packaging technologies

	(1) Quantity loss (%)	(2) Quality loss (%)	(3) ln (Firmness)	(4) TSS Brix°
Small plastic boxes vs. Palm crates	-0.585*** (0.146)	-5.920** (2.654)	0.195*** (0.023)	-0.077*** (0.019)
Large plastic boxes vs. Palm crates	-1.254*** (0.168)	-9.641*** (2.972)	0.192*** (0.025)	-0.103*** (0.019)
Large plastic boxes vs. Small plastic boxes	-0.669*** (0.098)	-3.721 (2.539)	-0.003 (-0.022)	-0.0256 (-0.014)

Source: Authors' calculations based on data from the 'Tomato Load Tracking and Sampling Assessment' carried out by FAO in Egypt, December 2018 to January 2019.

Note: Standard errors in parentheses. *** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1

Figure 3.10 shows differences in fruit attributes between packaging materials as the days progress after fruit transport. For example, fruit quantity losses become statistically lower in plastic containers only after the third day (panel A), while quality losses have a higher variance, and are not statistically different, with differences becoming apparent only when the full sample is compared. Fruit firmness, on the other hand, is measurably different immediately upon arrival at wholesale markets on day one (panel C). Differences in fruit maturity, as measured by TSS, as with quantity losses, are statistically significant from day three onwards.

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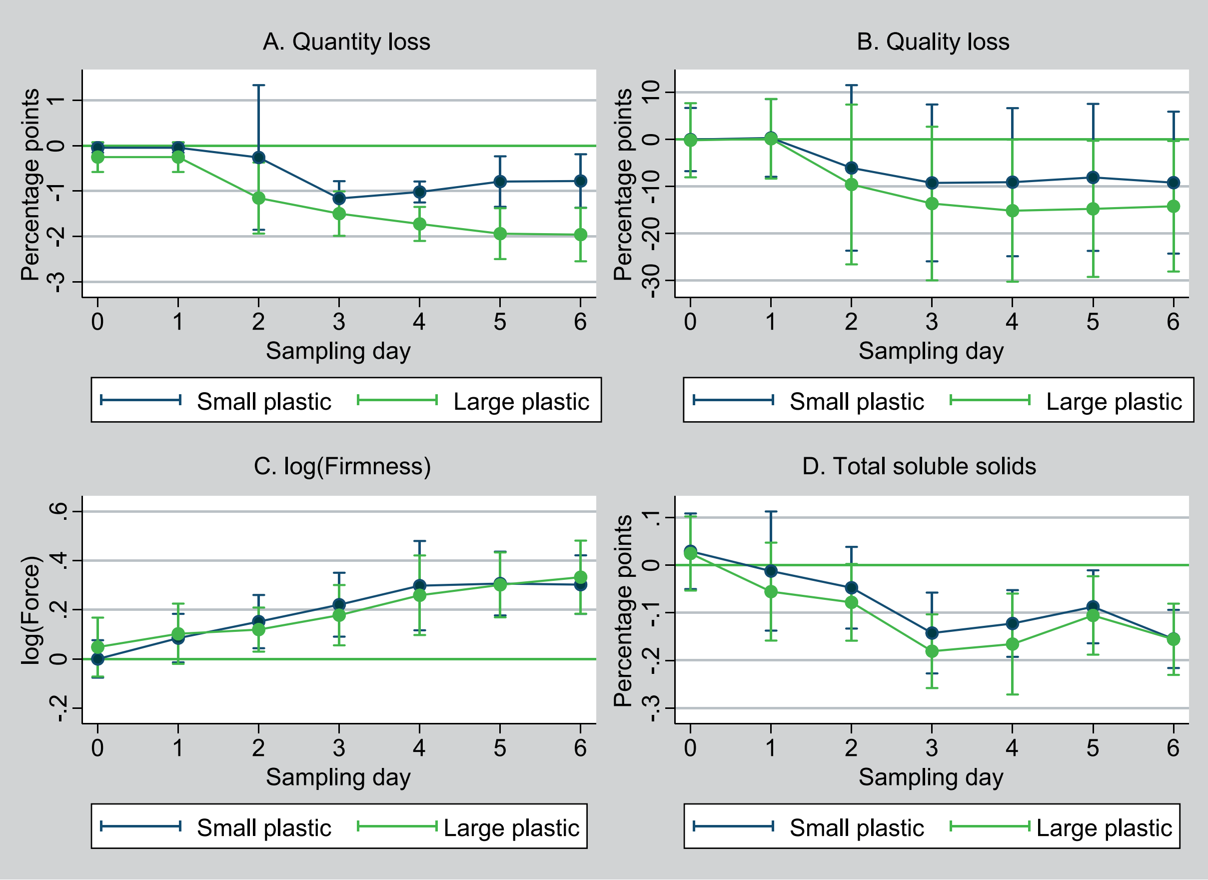
Figure 3.10 Marginal effects of package type on loss attributes by day, compared to palm crates



Source: Authors' calculations based on data from the 'Tomato Load Tracking and Sampling Assessment', carried out by FAO in Egypt, December 2018 to January 2019.

Note: Day 0 corresponds to measurements on day 1, at the farm but before transport. Error bars represent the 95% confidence intervals.

Although the improvements in fruit attributes associated with the use of plastic crates are statistically significant, it is important to highlight that these differences are low from an economic perspective. For example, the use of large plastic boxes reduces fruit quantity losses by 1.25 percent compared to palm crates. Given the precision in this point estimate, at most this reduction in losses would be 1.64 percent (the upper limit of the 99 percent confidence interval). In fact, it is gratifying that such a small difference is estimated with precision with the econometric model. These results force the question of whether or not it is economically attractive to use plastic crates instead of traditional palm crates in this Egyptian context. The answer depends on how many times plastic crates can be re-used. Large plastic crates cost EGP (Egyptian Pounds) 35 per unit bought in bulk (about USD 2 in 2018), and hold 20 kg of tomatoes, while palm crates also transport 20 kg of tomatoes, and cost EGP 10. According to expert opinion, plastic crates can be reused 100 times or last for two years, while palm crates can be reused 20 times or last for one year. The economic gain of using plastic bins is EGP 0.375 per bin (0.0125 loss reduction x 20 kg x EGP 1.5/kg tomato price). Therefore, if plastic crates can be used at least 40 times in a year, it is better to use plastic bins: the difference in cost is EGP 15 (35–20), which is exactly equal to the gain in revenues (EGP 0.375 x 40). Assuming a more limited amount of uses per year, one would have to discount costs and gains to compare present values. Assuming that boxes are to be reused 20 times in a year, and assuming a discount rate of 12 percent (reasonable for Egypt) plastic crates

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are only economically preferable if they can be used at least one time in a third year (i.e. if they exceed their expected durability). If one takes a lower turnaround and assumes that boxes are used only eight times per year, and palm crates are changed every year, then plastic crates become more economically efficient only after one use in the fourth year.[12] If, however, plastic crates can be reused for a fifth year, plastic becomes economically preferred over palm crates, even if there is no reduction in losses.

In conclusion, reusable plastic bins do in fact reduce fruit losses, but these reductions are so small (in part due to the price of tomatoes), that they become an economically efficient alternative only when they exceed their expected life cycle. The econometric results here show clearly that wholesalers are almost certainly behaving rationally when they prefer palm crates that lead to higher fruit loss rates. It is reasonable, however, to assume that a migration toward plastic containers should occur in the future, when either tomato prices increase, or traditional crates become more expensive as wages increase (as an expected outcome of development).

To interpret these results in the context of policy considerations, one should note that, while the type of technology introduced by the FAO experiment was likely economically similar to the traditional technology in terms of present conditions facing tomato value chain actors, plastic crates might in the future allow farmers to differentiate their product and access higher-value markets. The authors have observed in different types of markets in Cairo and Alexandria large differences in retail prices of tomatoes between hyper-markets, supermarkets and local groceries. Often high-end grocers sell tomatoes at prices that are three or four-fold that of geographically close hyper-markets, which in turn have higher prices than local street sales. Accessing higher-price markets could justify adopting more costly technologies, such as individual, plastic boxes, which these markets demand, both for reasons of quality control and storage. Accessing these markets, however, would require coordinated technological changes at several points along the value chain, including at the farm level, and some signalling, pass-through and sharing of the gains via differentiated prices. This suggests future study of the potential incentives and bottlenecks that might be slowing such coordination to date.

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[12] The present value of use of plastic is EGP 35, while the present value of use of palm crates is: $\sum_{t=1}^{T} \frac{10}{(1+\rho)^{(t-1)}}$, where ρ is the discount rate, and T, the number of years in each comparison. The difference of these costs needs to be lower than the present value of gains: $\sum_{t=1}^{T} \frac{g}{(1+\rho)^{(t-1}}$, if plastic is to be economically superior. The gain g is equal to the economic gain of each box, EGP 0.375 times the number of times the plastic box is reused each year.

Discussion and reflection on findings

The results of the case studies presented here, estimating determinants of losses at the farm level and disentangling the marginal economic benefits of different loss-abating actions, support the hypothesis that observed food loss is consistent with farmers behaving rationally. This analysis demonstrates the value of extending the analytical recommendations of de Gorter (2014), Koester, (2017) and Anriquez *et al.*, (2018) and the empirical example of Chegere (2018) to centre the FLW measurement problem in the context of value chain actors' decisions. Choices that eventually lead to observed food loss are linked to the additional costs and benefits of loss abatement, and so loss levels are unlikely to significantly deviate from economic efficiency from the point of view of the decision maker. The empirical analysis shows that for these specific case studies, losses are within the bounds of rational behaviour; to be precise, the benefits of adopting loss-reducing activities or technologies are not significantly higher than their costs. The implication for future FLW studies is that careful measurement of physical losses should be accompanied with a recording of relevant incentives: price of outputs and cost of loss-reducing alternatives.

In addition, the analysis on Egyptian tomatoes revealed an important caveat to the simplistic comparison of the loss-abatement potential of different technologies. The evidence demonstrates that the introduction of a loss-reducing technology concurrent with a traditional method confounded the identification of the source of losses and so, the estimates of the loss-reducing impact of the new technology was biased. Wholesalers apparently adjusted their behaviour to take advantage of the new technology – plastic crates – in the presence of the old, palm crates. With the introduction of plastic crates, higher-quality fruit were selected (more likely to survive and earn a higher price at final sale) for the more secure plastic cases. Researchers should take care to control for this confounding effect in future empirical studies.

Both cereal and dairy sectors are generally understood as having important economies of scale in primary production. This means that both industries are characterized by large fixed costs, which causes average costs to decline with farm size. In other words, larger farms have an economic advantage which usually manifests in farm size consolidation over time. This tendency toward consolidation has yet to be reflected in average farm sizes in Tunisia, with cereal farms having an area of only 6.5 hectares on average, and dairy farms having on average only four cows. Just as an example of consolidated industries, the average wheat farm size in Kansas is 170 hectares, and an average dairy farm in dairy producing Wisconsin has 135 cows per farm.

With respect to overall costs, the data for these case studies do not contain the type of information required to test for economies of scale, which would be important especially for Tunisian grains and dairy. The data are available to examine the relationship between farm size and losses and show that percentage losses of wheat and milk are reduced with increasing farm size. Although this is an additional economic force that promotes farm consolidation, it is also an indicator of the response of farm losses to price changes. The response of losses to scale among Tunisian farms indicates that farmers will reduce loss with output price increases. This result highlights the importance of having adequate pricing policies as part of an overall policy environment to promote an efficient (low-loss) productive sector.


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Farm consolidation may not happen rapidly in Tunisia, either because scale economies are more contained in these productive sectors, or because existing, low-productivity small farmers do not have sufficiently attractive alternatives to exit agriculture. Hence, although larger scale may be the solution for higher productivity and lower losses in these industries over the long run, in the short run policymakers should pay attention to lower productivity and higher losses in smaller farms, particularly given their prevalence in Tunisia. This paper provides some suggestions based on the results presented, where in different forms the potential for promoting collective action is highlighted. Nevertheless, a complete welfare analysis of small farmers should examine not only losses but productivity more generally. For example, in the case of wheat farms, this study estimates that the benefits to improving the use of mechanical harvesters are significant even for small farms. This does not mean, however, that this is necessarily the best way to help small and poor farmers. For example, if better seeds, or an improved fertilization schedule has a larger increase in yields than comparable reductions in harvesting losses, at a comparable cost, then the best policy would be the former. This is why, in order to understand in depth the impact of losses on farmer welfare, the analysis should be carried out as part of a larger effort of accounting for farm productivity, as suggested in Anriquez ***et al***. (2018). Finally, a simple recommendation would be that future loss studies not only focus on overall farm productivity, but that they use independently monitored loss measurements, as errors in perception may limit the ability to analyse losses, particularly when farmer-estimated loss rates are low.

04

Policy considerations

Policy considerations

This report has emphasized that analytical questions concerning FLW should be based on an understanding of the set of incentives facing individual actors along the value chain and how the microeconomic decisions of farmers, intermediaries and consumers aggregate to determine the functioning and productivity of the agrifood system as a whole. Analysts and policymakers seeking to assess and respond to the social and economic costs of FLW should do so in terms of resources lost at different stages of food value chains. While advances in conceptual modelling, identification and measurement have been made (e.g., de Gorter, 2014; Bellemare, 2017), there is no simple formula to aggregate FLW meaningfully for policy purposes because agrifood systems are highly complex in the production, transportation and transformation of products as materials move from farmers' fields to consumers' tables. Little attention has been given in the literature to modelling and understanding the relationships between prices, production and loss-abatement activities at particular stages of the agrifood system and their upstream and downstream impacts. The analytical approach in this report allows for several policy-relevant. First, policy analysts should take the perspective of economic efficiency when making recommendations regarding the use of scarce resources in the context of FLW. Analysts should model and understand the relationships between loss and waste-abatement decisions and incentives in a way that they can be linked with observables and econometric models. The sections above have discussed and illustrated the decision rules of three types of market participants, which allow comparative-static results regarding the link between product prices and FLW at the individual level and in the context of a agrifood system-wide market equilibrium. An important principle analysed above is that prices communicate decisions about productivity across the value chain to other actors. And one important type of productivity decision is with respect to rates of FLW at different nodes of the agrifood system. Actions taken that impact FLW propagate upstream and downstream within the value chain leading to overall levels of FLW in the system as a whole.

Second, a rigorous cost-benefit analytical approach should be the aim of good policy planning and evaluation, allowing for a better understanding of how people make decisions leading to FLW, subject to the state of the environment in which they operate, including policies and institutions. One major conclusion that derives from this perspective is that different actors with different attributes would react differently to incentives. Therefore, a blanket approach to calculating food losses – especially one based on physical quantities – will likely fail to understand the mechanisms driving FLW. More importantly in the context of seeking to address sustainable consumption and production goals, reducing FLW by any given amount must be accompanied by incentives and the use of resources that have some – perhaps large – opportunity costs in terms of foregone investments in other policies and projects to promote development and human welfare.

Third, more specifically with respect to data and analysis, whilst aggregate food loss rates may be interesting and probably the preferred way of tracking the progress of quantity-focused goals, they are not by themselves sufficient to inform good policymaking and evaluation. At a minimum, policymakers will require loss information by specific nodes along the value chain to identify and prioritize critical points for possible interventions. Furthermore, the very measurement and monitoring of losses at stages of the value chain requires the use of resources that must be diverted from other activities. Therefore, some attention should be paid to the design and intensity of programs aimed at measuring and monitoring food losses to make them as efficient as possible. In addition, loss measurement and valuation cannot be done in isolation, but rather within the context of a more complex productivity analysis. Analysts should not lose sight of the larger picture; that farmers and other operators along the food value chain balance food loss reductions against the benefits of other productive activities, such as dedicating more time and money to harvesting or to better fertilize lands; and households balance food waste reductions against the benefits of other welfare-improving activities, such as spending more time with children. In short, data and information systems meant to support policies to reduce FLW and programs to promote loss-reducing technologies should be designed with cost-benefit analyses in mind. Technologies with great advertized loss-reduction potential would face difficulties being adopted by agents if the net result is not beneficial, taking into account all resources at hand, not merely food. Quantity data is not enough; prices, input use, and cost data are important for policy design.

Fourth, there is an important role for quantity monitoring. Most clearly, the efforts of FAO and other agencies to measure physical losses are very useful for answering questions related to policymaking and evaluation that might be helpfully addressed by comparative studies and benchmarking. For example, this data can be useful to understand whether there exist differential regulatory frameworks that lead to possible differences in investments to abate FLW. In the case of comparisons between countries, analysts can use quantity monitoring to look for bottlenecks and coordination problems in a country that might lead to higher-than-expected rates of FLW from the perspective of what is usually encountered in other similar countries. Some FLW problems could be related to specific distorting/rent-seeking policies, giving the country's policymakers an additional reason for policy reforms. Specific regulatory regimes and subsidies could also sometimes be obstacles to investments in loss-reducing technologies and intermediation activities that are absent in a country but not in others.

Another source of differences in rates of FLW could be with respect to the role of industry organization and structure in determining the incentives to invest in improved efficiency. Loss quantity monitoring can assist decision-makers to better understand by comparison with other realities how market organization/structure affect the levels of FLW, and how more atomized or demanding markets may lead to higher or lower rates of food losses. Certainly, more work must be done on modelling and understanding the structure of industries and its relation to loss rates. A comparison of quantity measurements of food loss across food market chains with distinct industry organizations would allow a first-order estimate of the correlation of market structure with system efficiency. In addition, the nature of the product and target markets might lead to different market structures that would then have implications for FLW. For example, benchmarking may help analysts to understand if a limited number of (perhaps cooperating) monopsonistic and monopolistic wholesale intermediaries in the fresh tomato value chain in Egypt adjust the flow of product (and thus price) to domestic consumers by altering rates of loss. Or perhaps if a lack of competition in certain markets may propel the reduction of productivity-enhancing investments related to loss abatement. Or by contrast, if participants in Egypt's export-grape value chain, facing demanding foreign buyers and international competition, have rates of food loss that are more comparable to their domestic peers in other horticultural sectors or to their international counterparts in the table grape sector.

Benchmarking FLW rates within a country or industry is also valuable, giving governments a role in information dissemination. Although one would expect actors in the same industry to face the same regulatory system and technology, there are likely interesting differences in FLW rates that depend on geography, firm sizes and perhaps other attributes. Benchmarking may be useful to assess differences within a country or industry due to different technologies that lead to different costs to abate losses. If the rate of FLW for some firm or subset of firms is 'large' in comparison to the benchmark, then further cost-benefit analysis would be required to check if 'large" in quantity terms is also significant in economic terms. If so, it would invite more research into the mechanisms or determinants to explain why the differences in FLW might occur.

Fifth, the overall use of quantity monitoring of FLW could serve as a type of warning system for decision-makers and within governments about the need for re-evaluating priorities related to enhancing the productivity of agrifood systems. Perhaps there is too much emphasis on increasing farm-level yields and not enough on other stages of the agrifood system. Policy analysis might want to give FLW monitoring a dynamic and future orientation, recognizing that the agrifood system is not static, and that potential policy biases of the past should not be cemented into the response of today's policy to improve the agrifood system of the future. As agrifood systems evolve, policy regimes might also have to evolve in order to avoid increased FLW rates that might result from inappropriate regulations or other policy restrictions. Furthermore, information from the monitoring of FLW can be used to facilitate private decision making. Information regarding FLW at the firm might be seen as a type of public good and used for credible signalling from more FLW-efficient producers/intermediaries to consumers concerned about reducing FLW. This type of monitoring could facilitate the creation of niche markets, such as that for 'ugly' food. At the minimum, where evidently large rates of FLW are documented to exist, this should signal to private investors that there are potential returns to be had in improving efficiency via the use of existing technologies and methods, or via research into new technologies.

Sixth, and finally, as this report has emphasized, total FLW is determined by the agrifood system operating as a whole. In any policy design focused on reducing FLW for whatever reason, analysts and government decision-makers should recognize that attempting to reduce FLW at one stage of the value chain will affect other actors, perhaps negatively, at other stages. And furthermore, the net effect on FLW is not obvious, perhaps increasing or decreasing FLW at other stages.

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Appendices

Appendices to Introduction

Table A.1 Estimation of food losses in grapes and tomato value chains in Egypt, using the survey and sampling methods 2016–2017 (percentage losses)

Product	Governorate (year)	Method	Farm Level	Wholesale	Retail
Grapes	Nubaria (2016–2017)	**Survey**	18.6	5.3	6.7
		Sampling	10.3	16.41	19.05
Tomato	Nubaria and Sharkia (2016–2017)	**Survey**	18	6	7
		Sampling – Quantity loss	35	40	29
		Sampling – Quality loss	12	19	29

Sources: FAO. 2021a. Food Loss Analysis for Grapes Value Chains in Egypt. Cairo. (also available at https://www.fao.org/publications/card/en/c/CB4676EN/). **& FAO**. 2021b. Food Loss Analysis for Tomato Value Chains in Egypt. Cairo. (also available at https://www.fao.org/publications/card/en/c/CB4733EN/).

Table A.2 Estimation of food losses in apple value chain in Lebanon, using survey and sampling method 2016 (percentage losses)

Product	Governorate (year)	Farm Level	Wholesale	Retail (Waste)	Governorate (year)	Loss type	Storage
Apples	Akkar, Bek'a, Mount Lebanon (2016)	2–10	4	1	Akkar (2016)	**Physical loss**	4
						Damage	96
					Beka'a (2016)	**Physical loss**	3
						Damage	97
					Mount Lebanon (2016)	**Physical loss**	4
						Damage	11

Source: Chahhal, H., Chahine, H., & Tohme, S. 2017. Case Study Report on Food Losses in Apple Value Chain in Lebanon. FAO internal document. Cairo, FAO.

Table A.3 Estimation of food losses in wheat and fruit value chains in Morocco, using survey and sampling method 2015 (percentage physical losses)

Product	Region (year)	Harvest	Storage	Transport	Wholesale	Retail	Processing
Soft Wheat	Saiss (2015)	10	14	1	10		2
Apple	Midelt (2015)	10	19	2	14	9	---
Citrus	Gharb (2015)	5	1–2	2	1–2	---	---
Fig (fresh)	Taounate (2015)	---	---	---	5		---
Fig (dried)	Taounate (2015)	---	2–5	---	Minimal	2–5	5–10
Prickly pear	Ait Baamrane, Rhamna (2015)	16	---	---	---	---	---
Dates	Tafilalet, Draa (2015)	14	19	2	Minimal	---	---

Source: FAO. 2016b. Rapport de synthèse sur la réduction des pertes post-récolte des produits alimentaires au Maroc. FAO internal document. Rabat.

Table A.4 Estimation of food losses in vegetable and fruit value chains in Palestine, using survey and sampling method 2017–2018 (percentage physical losses)

Product	Region (year)	Farm Level /Harvest	Wholesale	Collection Centres	Ripening Chambers	Transport	Retail
Tomato	West Bank and Gaza Strip (2017–2018)	7.4	7.5	---	---	6.3	13.8
Sweet Pepper	West Bank and Gaza Strip (2017–2018)	8.1	10.6	---	---	6.1	20.2
Avocado	Qalqilya and Tulkarem, West Bank (2017–2018)	9.2	---	21.3	6.0	8.7	16.1

Sources: FAO and MAS. 2020a. Food Loss Assessment: Causes and Solutions in the Avocado Value Chain in Palestine. Jerusalem, FAO and Palestine Economic Policy Research Institute (MAS). & **FAO and MAS**. 2020b. Food Loss Assessment: Causes and Solutions in the Tomato and Sweet Pepper Value Chains in Palestine. Jerusalem, FAO and Palestine Economic Policy Research Institute (MAS).

Table A.5 Estimation of food losses in cereals and milk value chains in Tunisia, using survey method 2016–2017 (percentage physical losses)

Product	Governorate (year)	Farm Level				Collection Centre	Transport *	Transformation
		Total	At harvest	At field storage	To transport			
Cereal	Bizerte (2016–2017)	4.6	3.6	0.4	0.8	0.2	---	---
	Siliana (2016–2017)	7.3	5.4	3.4	2.0	0.4	---	---
Milk	Bizerte (2017)	2.0	---	---	---	2.3	2.1	3.5
	Mahdia (2017)	0.7	---	---	---	1.8	0.8	3.5

Sources: FAO. 2020a. Analyse des pertes alimentaires: causes et solutions (Étude de cas de la chaîne de valeur céréalière en Tunisie). Tunis. & **FAO.** 2021c. Analyse des pertes alimentaires: causes et solutions — Étude de cas de la chaîne de valeur du lait en Tunisie. Tunis. (also available at https://www.fao.org/documents/card/en/c/ca7334fr/).

Appendices to Section 1

Appendix 1.1. Different Definitions of Food Losses

FAO definition, from FAO (2019).

"FLW is understood as the decrease in quantity or quality of food along the food supply chain… *Food loss* is the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retail, food service providers and consumers. *Food waste* is the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food services and consumers."

US ERS Definition, from Buzby *et al.* (2014).

"Food loss represents the amount of food postharvest, that is available for human consumption but is not consumed for any reason. It includes cooking loss and natural shrinkage (for example, moisture loss); loss from mould, pests, or inadequate climate control; and food waste. Food waste is a component of food loss and occurs when an edible item goes unconsumed, as in food discarded by retailers due to color or appearance, and plate waste by consumers"

European Union Definition, from Stenmarck *et al.* (2016)

"Food waste is any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed (including composed [sic], crops ploughed in/not harvested, anaerobic digestion, bioenergy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea)"

US EPA Definition, from U.S. Environmental Protection Agency (2017)

"The amount of food going to landfills from residences, commercial establishments (e.g., grocery stores and restaurants), institutional sources (e.g., school cafeterias), and industrial sources (e.g., factory lunchrooms). Pre-consumer food generated during the manufacturing and packaging of food products is not included in EPA's food waste estimates."

An academic definition, from Bellemare *et al.* (2017)

Let $\bar{y}$ denote the quantity of food produced. Let $k \in \{1, \dots, N\}$ denote the N potential productive uses for food. For each productive use, a certain amount of food $y_k < \bar{y}$ is employed. Food waste is any quantity $w > 0$ such that $w = \bar{y} - \sum_{k=1}^{N} y_k$.

Appendix 1.2. A simple microeconomic model for actors' decisions

This section presents a simplified profit maximization model for the three basic actors most important to the determination of FLW: farmers, intermediaries, and final-buyers/consumers. The models of individual choices are simple, but are meant to account for the relevant factors in decisions taken by these three parties, which eventually result in total FLW, looking at the food value chain as a whole. Finally, this section demonstrates how consumer waste changes as consumers (countries) become wealthier using the same consumer welfare maximization model expressed as the dual problem of cost minimization.

The farmer

The first participant in the food value chain is the farmer, whose objective it is to maximize net revenues. The economic problem they face can be expressed as:

$$\max_{K,L,\mathbf{x}} p_1\left[1 - l_1\ (K,L,\mathbf{x};Q_0\ )\right]Q_0\ (K,L,Z,\mathbf{x}) - rK - wL - \omega\mathbf{x} \qquad (1)$$

They need to maximize the value of physical output $Q_0\ (K,L,Z,\mathbf{x})$, which is a product of used inputs: capital (K), labour (L), land (Z), and other variables and inputs (a vector, $\mathbf{x}$), like fertilizers, fuel, pesticides, etc., net of costs determined by the corresponding market unit prices (r,w,ω). Part of this output (a share $l_1\ (K,L,\mathbf{x};Q^0\ )$) is lost at harvest and during post-harvest activities. However, inputs used can impact the rate of losses, as for example, more labour employed at harvest can reduce the share of output lost. From the first order condition for maximizing revenues with respect to capital the model obtains the following relationship that can be extended to other inputs of production as well:

$$\left[\frac{\partial Q_0}{\partial K}\frac{K}{Q_0} - \frac{\partial l_1}{\partial K}\frac{K}{l_1}\cdot\left(\frac{l_1}{(1-l_1\ )}\right)\right] = \frac{rK}{p_1[1-l_1\ ]Q_0} \qquad (2)$$

This relation states that the difference between the output elasticity of the input (capital in this case) and elasticity of the loss function with respect to the input times the relative losses – $(l_1\ /(1 - l_1\ )$ which moves between 0 and infinity – need to equate to the input's revenue share. For inputs that have an impact in the loss function there are three relevant cases to consider. The simplest case is an input that only impacts losses and not production directly, for example the case of pesticides. In that case, the marginal impact of the input on losses needs to be negative, i.e. the use of the input reduces losses, in order to equate to a positive revenue share. The second case refers to an input like labour, which with more intensive use, increases physical output and reduces losses. Finally, there is a more interesting case, which can happen with inputs like capital, and the case of mechanization in particular. Moving into mechanized harvesting increases losses $(l_1\ /(1 - l_1\ )$, which can only be economically sustained by high productivity of capital in production, and hence, a large output elasticity of the input, capital.

The intermediaries

Intermediaries in the agrifood system behave differently from primary producers. For each intermediary, food is an input which they want to transform, and they collect revenues from this process of adding value. The transformation can be as simple as moving food from point A to B or wrapping in cellophane paper, or more complex transformations like processing food into a fundamentally new product. All intermediaries, however, face clear economic incentives to reduce losses, because food lost is the loss of an input which they want to transform and sell. The economic problem of the intermediary can be formalized (in the case of the first intermediary) as:

$$\max_{\mathbf{x},Q^1} p_2 Q_2 - p_1 Q_1 - \omega \mathbf{x} \qquad (3).$$

The intermediary will maximize their revenues of selling an output Q^2, net of the cost of inputs used $(\mathbf{x})$ and perhaps the most important input, upstream food: $Q_1 = [1 - l_1]Q_1$. For the intermediary, with output and losses determined upstream, the choice is how much food input, Q_1, will be used. The intermediary also choses losses, given abatement technology, and output determined by a transforming technology $G()$:

$$Q_2 = \left[1 - l_2(\mathbf{x})\right] G(\mathbf{x}, Q_1) \qquad (4).$$

In the case of simple transformations, it makes sense to think of the technology $G()$ as being linear, but in general, from the first order conditions of any given, non-food input, the following relationship can be derived:

$$\left[\frac{\partial Q_2}{\partial x_i}\frac{x_i}{Q_2} - \frac{\partial l_2}{\partial x_i}\frac{x_i}{l_2} \cdot \left(\frac{l_2}{(1-l_2)}\right)\right] = \frac{\omega_i x_i}{p_2[1-l_2]Q_2} \qquad (5).$$

The reader will note that condition (5) is equivalent to condition (2): the difference between the output elasticity of the input, and elasticity of the loss function with respect to the input multiplied by the relative losses, needs to equate to the input's revenue share. Relation (5) seems to suggest that there are possible trade-offs in input use between greater productivity and higher losses. However, these trade-offs are not possible in the case of simple transformations, like transportation, or say converting wheat into flour, or flour into pasta. In these cases, higher losses can only translate into lower production, as an identifiable physical product is moving along the value chain. The intuitive result is that the food intermediary has clear economic incentives to minimize losses; relationship (5) shows that it mathematically stands on the assumption that unlike in primary production, there are no inputs with loss trade-offs, i.e. which increase losses but also highly increase output. These latter trade-offs are not the norm along the value chain, but could theoretically be possible in the case of drastic changes in the farm good where significant value is added via food loss augmentation. Most inputs however, used between the farm and the end-consumer, are either exclusively loss abating, or like fuel, capital, labour, etc., are output increasing and loss reducing.

The consumers

Upstream from the consumer along the value chain, food is either an output, or an input that is transformed or modified to be sold as a product with additional value added. Along these stages of the agrifood system, decision-makers will generally abide by the rule of reducing food losses until the costs of further reductions in losses exceeds the benefit of that additional loss reduction. The end-consumer, however, has different incentives. He or she will buy and consume food, deriving wellbeing from this consumption, constrained in two notable ways: the given wealth or income that limits consumption possibilities; and time constraints which limit the opportunity for undertaking different activities, like working and earning income, going to the market for food, reducing food losses and resting/leisure (which is time consumed). A simple formalization of the consumer's problem, following standard consumer theory, can be given by:

$$\max_{F, Q_o, L_C} U(F, Q_o \, ; L_C) \qquad (6),$$

that is, maximization of utility that depends on food consumed F, other goods consumed Q_o, and leisure L_C. This maximization is constrained by a standard budgetary restriction: $p_f Q_f + p_o Q_o \leq wL_M$, where the value of purchased food $Q_f$and other goods Q_o, must not be larger than income, which in turn is derived by working L_M time at the ongoing wage rate w. Purchased food is prepared, and some of it is lost at home, and following a simple transformation it is converted into consumed food F, or simply put, meals $F = \left[1 - l_f(L_l)\right] Q_f$, with labour employed in loss abatement L_l, assumed to be loss reducing $l_f' < 0$. Finally, there is a time constraint. Activities, namely work, leisure, and food loss abatement need to equal total available time: $T = L_C + L_M + L_l$. Using the price of other goods as the numeraire, i.e. $p_o \equiv 1$, the consumer problem as an unconstrained maximization problem can be defined as:

$$\max_{Q_f, L_M, L_l} U(\left[1 - l_f(L_l)\right] Q_f \, , wL_M - p_f Q_f \, ; T - L_M - L_l) \qquad (7),$$

Using the three first-order conditions, how losses and food consumption relate to real income w/p_f can be shown as:

$$Q_f \cdot \frac{-l_f'}{(1-l_f)} = \frac{w}{p_f} \qquad (8).$$

To gather the equilibrium effect of raising real incomes on time spent on loss abatement requires a complete comparative static analysis, provided in the mathematical appendix. However, expression (8) can be used to distil what happens. Assuming that both food and leisure are normal goods, when real incomes rises, food consumption grows Q_f, while leisure consumption, L_C, falls.[13] The fall in leisure needs to be compensated with an increase in time allocated to productive activities, L_M, and/or L_l. Time working will increase, because the marginal return to work effort w has increased. On the other hand, what happens with time allocated to food-saving activities depends on the expression $-l_f'/(1 - l_f)$. This expression is assumed to depend negatively on L_l, i.e. $l_f'' > 0$, which is the curvature property to assume if one believes that there are diminishing marginal returns to loss-abatement efforts. This is the reasonable assumption, consistent with the law of diminishing marginal returns, that the amount of time required to reduce losses from, say 90 to 80 percent is lower than the effort required to reduce losses from 11 to one percent. Given this assumption, if the consumer is poor and responds to the rise in $\frac{w}{p_f}$ with sharp increases in food consumption, they may actually also increase their loss abatement-efforts. However, surely in the case of a wealthier consumer (with a low income elasticity for food demand, as suggested by Engel's law) their labour effort in food abatement needs to go down so that their food abatement effort returns, $-l_f'/(1 - l_f)$, increase as work effort returns w have also increased.

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[13] Standard microeconomic theory teaches that for poorer consumers, rises in real income are dominated by substitution effects, which means that less leisure is consumed, and more effort is devoted to productive activities: save food (L_l) and generate income L_M. For wealthy consumers, income effects may dominate instead, and may result in a reduction of time devoted to productive activities.

Income and household food loss abatement behaviour

To show how loss-reducing effort L_l responds to increases in wages, and also to the cost of time in this model, the same consumer model is represented as defined above, but expressed as the dual problem of cost minimization:

$$e(p_F, p_o, w; U) + wL_l = wT \tag{A1}$$

$$L_M = T - e_w(p_F, p_o, w; U) - L_l \tag{A2}$$

$$\frac{-p_f l_f^{'}}{(1-l_f)^2} \cdot e_{p_F}(p_F, p_o, w; U) = w \qquad \text{(A3).}$$

Equations (A1) – (A3) define the cost minimization problem, and jointly solve for the three unknowns of this model, U, L_M, and L_l, while the consumption levels $(F, Q_o\ , L_C)$ are determined by the price derivatives of the expenditure function:

$$e(p_F, p_o, w; U) \equiv \min_{F, Q_o\ , L_l} \{p_F F + p_o Q_o\ + wL_c \mid U(F, Q_o\ ; L_C) \leq U\} \qquad \text{(A5).}$$

Note that in this expenditure function the consumption of prepared food F, depends on its shadow price:

$$p_F = \frac{p_f}{[1-l_f(L_l)]} \qquad \text{(A4),}$$

which is a loss-adjusted price, different from the price of purchased food p_f.

The effect of wages on time spent on the kitchen and doing other food preparation activities, like going to the market, is obtained using equation (A3). Notice that equation (A3) is exactly the same relationship presented in equation (8), it equates the marginal return of spending time in food-related activities $\frac{-l_f^{'} p_f Q_f}{(1-l_f)}$, with the marginal return of time spent working for a wage w. Obviously, this is the optimal rule of how to allocate time between the activities which derive disutility on the consumer: L_M and L_l. Totally differentiating equation (A3) with respect to L_l and w, the marginal effect of increasing the wage rate on time spent on food preparation, or food loss abating activities, is obtained both in marginal effects and elasticities:

$$\frac{\partial L_l}{\partial w} = \frac{\left[1 + \frac{p_f l_f^{'}}{(1-l_f)^2} e_{p_F, w}(p_F, p_o, w; U)\right]}{\left[-\left(\frac{l_f^{''}(1-l_f) + 2(l_f^{'})^2}{(1-l_f)^3}\right) p_f e_{p_F}(p_F, p_o, w; U) - \left(\frac{p_f l_f^{'}}{(1-l_f)^2}\right)^2 e_{p_F, p_F}(p_F, p_o, w; U)\right]} = \frac{[1-\epsilon_{F,w}]}{w\left[\left(\frac{l_f^{''}}{l_f^{'}} + \frac{2l_f^{'}}{(1-l_f)}\right) - \epsilon_{F,p_F} \cdot \frac{w}{p_F F}\right]} \qquad \text{(A6).}$$

Expression (A6) can be attributed with high likelihood to poor consumers, and with certainty to wealthy consumers. The numerator is most likely positive for poor consumers, and certainly positive for wealthy consumers. The sign of the numerator depends on the elasticity of food (meals, or prepared foods) with respect to income/wages, $\epsilon_{F,w}$, and note that it is not the elasticity of purchased food with respect to w. If it is assumed that food consumption is a time-consuming activity (a reasonable assumption), then this elasticity is positive, as food consumption and leisure would be complements. However, this complementarity ought to be very low, because this is the complementarity between leisure, and time spent consuming food, and not preparing food, which in this model is explicitly accounted for through L_l. In the case of a wealthy consumer, $\Delta F \rightarrow 0$, because they are at or near food consumption satiation; food expenditures $(p_f Q_f)$ may still grow, but the amount of food F, i.e. meals consumed, would not change and hence $\epsilon_{F,w} \rightarrow 0$. The sign of the denominator should tell us the sign of the derivative, and it is likely positive for very poor consumers and certainly negative for rich consumers, if assumed, as in the text, decreasing marginal returns in loss abatement efforts. The elasticity of food consumption with respect to its own price ϵ_{F,p_F} is negative given the concavity requirements of the expenditure function. Since it is food consumption, it is known that for poor consumers who are far from satiating their consumption needs, this elasticity may be high, but converges to zero at or near food (meal) consumption satiation.[14] Finally, there is the term $(\frac{l_f''}{'}+\frac{2l_f'}{(1- \quad)})$ which is certainly negative given that there are decreasing marginal returns to labour abatement, $l_f'' > 0$. It reflects the fall in the returns to food loss abatement by increasing loss-abatement efforts L_l (for a given food expenditure level). Thus, for the very poor consumer, $\frac{\partial L_l}{\partial w}$ may be positive, but there exists an income level at which this marginal effect becomes certainly negative. Let us provide the intuition for this result: a very poor consumer, when faced with an increase in wages, can now consume more. They will spend most of their additional income on food, and will obtain that additional food by increasing their purchases of it, and will increase efforts in the kitchen to reduce losses. However, the case of the wealthier consumer is simpler; when they observe a higher wage, they will consume less leisure: $e_{w,w}(p_F, p_o, w; U) < 0$. This means that they will increase time spent on other (productive) activities: L_l and L_M. However, as wages increase, so too does the marginal return on effort spent working w, so they need to increase their marginal returns to food loss abatement: $\frac{-l_f' p_f Q_f}{(1-l_f)}$ As they are a wealthy consumer, and Q_f is not rising fast enough, they need to reduce effort spent on food loss abatement to increase returns on food loss abatement and equate them to the now higher returns on work effort.

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[14] Notice that the discussion of food demand compensated elasticities changing with income is not new in the literature. Please see (Timmer, 1981) for a discussion consistent with the arguments presented here.

Appendices to Section 2

Mathematical Appendix: A market model of the determination of FLW

This section shows mathematical details and proofs of the model presented in the text.

Farmers

Taking derivatives of the first order conditions (3) of the profit maximization problem presented in (2), the Hessian matrix of second-order conditions is derived:

$$H \equiv \begin{bmatrix} -c_{yy} & p_f - c_{y\alpha} \\ p_f - c_{\alpha y} & -c_{\alpha\alpha} \end{bmatrix},$$

where c_{ij} represent the second derivatives of the cost function. This matrix is taken to be negative definite to satisfy the second-order conditions for profit maximization.

The comparative statics of an increase in price, p_f, are then given by

$$\begin{bmatrix} -c_{yy} & p_f - c_{y\alpha} \\ p_f - c_{y\alpha} & -c_{\alpha\alpha} \end{bmatrix} \begin{bmatrix} dy \\ d\alpha \end{bmatrix} + \begin{bmatrix} \alpha \\ y \end{bmatrix} dp_f = \begin{bmatrix} 0 \\ 0 \end{bmatrix}.$$

Inverting the Hessian and collecting terms gives the result:

$$\begin{bmatrix} \frac{dy}{dp_f} \\ \frac{d\alpha}{dp_f} \end{bmatrix} = \begin{bmatrix} \frac{c_{\alpha\alpha}\alpha + (p_f - c_{y\alpha})y}{\Delta} \\ \frac{c_{yy}y + (p_f - c_{y\alpha})\alpha}{\Delta} \end{bmatrix} \tag{A1}$$

where $\Delta \equiv |H| = c_{yy}c_{\alpha\alpha} - (p - c_{y\alpha})^2 > 0$ is the determinant of H, which is positive given that the matrix H is negative definite. Relation (A1) proves Proposition 2, but further manipulation is required to transform this relationship into elasticities. First, note that from the first-order conditions of profit maximization, $p = c_y/\alpha = c_\alpha/y$, and with Young's theorem, $c_{\alpha y} = c_{y\alpha}$, therefore the cross elasticities of marginal cost are equal: $c_{\alpha y}y/c_\alpha = \varepsilon_{\alpha y} = \varepsilon_{y\alpha} = c_{y\alpha}\alpha/c_y$. Using these relations in the expression $c_{yy}y + (p_f - c_{y\alpha})\alpha$, and dividing by the positive marginal cost c_y, it can be shown that the sign of $\frac{d\alpha}{dp_f}$ is determined by the expression $\varepsilon_{yy} + 1 - \varepsilon_{y\alpha}$, as shown in the text.

Furthermore, using the same relationship (A1) it can be shown that the total quantity sold will certainly increase with an increase in product price:

$$\frac{d(\alpha y)}{dp_f} = \frac{d\alpha}{dp_f}y + \frac{dy}{dp_f}\alpha = \frac{1}{\Delta}(c_{yy}y^2 + 2(p_f - c_{y\alpha})\alpha y + c_{\alpha\alpha}\alpha^2)$$

This expression is unambiguously positive, as:

$$\frac{d(\alpha y)}{dp_f} = \frac{1}{\Delta}\begin{bmatrix} \alpha & y \end{bmatrix} \begin{bmatrix} c_{\alpha\alpha} & p_f - c_{y\alpha} \\ p_f - c_{y\alpha} & c_{yy} \end{bmatrix} \begin{bmatrix} \alpha \\ y \end{bmatrix} = \frac{1}{\Delta}\begin{bmatrix} y & \alpha \end{bmatrix} \tilde{H} \begin{bmatrix} y \\ \alpha \end{bmatrix} > 0 \qquad \text{(A2)},$$

where $\tilde{H} = \begin{bmatrix} c_{yy} & p_f - c_{y\alpha} \\ p_f - c_{y\alpha} & c_{\alpha\alpha} \end{bmatrix}$ is a positive definite matrix (due to the Hessian matrix H being negative definite). This proves Proposition 1.

To prove Proposition 3, note that:

$$\frac{dL_f}{dp_f} = \frac{dy}{dp_f}(1-\alpha) - \frac{d\alpha}{dp_f}y = \frac{dy}{dp_f} - \frac{d(\alpha y)}{dp_f}.$$

Continue using the definitions presented in (A1) and (A2). From (A1), it can be shown that:

$$\frac{dy}{dp_f} = \Delta^{-1} p_f y(\varepsilon_{\alpha\alpha} + 1 - \varepsilon_{y\alpha}),$$

and from (A2),

$$\frac{d(\alpha y)}{dp_f} = \Delta^{-1} p_f \alpha y\left[(\varepsilon_{\alpha\alpha} + 1 - \varepsilon_{y\alpha}) + (\varepsilon_{yy} + 1 - \varepsilon_{y\alpha})\right].$$

Using these expressions, it can be shown that:

$$\frac{dL_f}{dp_f} = \Delta^{-1} p_f y\left[(1-\alpha)(\varepsilon_{\alpha\alpha} + 1 - \varepsilon_{y\alpha}) - \alpha(\varepsilon_{yy} + 1 - \varepsilon_{y\alpha})\right],$$

which is used to construct the arguments presented in Proposition 3.

As in the case of the farmer, intermediaries maximize net profits from selling a transformed or processed product given prices of inputs, including the agrifood product, and given technology as formalized in equations (6). Again, differentiating the first-order conditions (7) allows one to construct the Hessian matrix of second-order conditions of the profit maximization problem of the intermediary:

Intermediaries

$$\mathrm{K} = \begin{bmatrix} -\kappa_{q_f q_f} & p_b - \kappa_{q_f \beta} \\ p_b - \kappa_{\beta q_f} & -\kappa_{\beta\beta} \end{bmatrix},$$

where again, κ_{ij}, refers to the second derivatives of the cost function $\kappa(w, q_f, \beta)$, defined in (6).The comparative statics of an increase in the price of the purchased agrifood product, p_f, is given by,

$$\begin{bmatrix} -\kappa_{q_f q_f} & p_b - \kappa_{q_f \beta} \\ p_b - \kappa_{\beta q_f} & -\kappa_{\beta\beta} \end{bmatrix} \begin{bmatrix} dq_f \\ d\beta \end{bmatrix} - \begin{bmatrix} 1 \\ 0 \end{bmatrix} dp_f = \begin{bmatrix} 0 \\ 0 \end{bmatrix}.$$

Inverting the Hessian and collecting terms gives the result:

$$\begin{bmatrix} \frac{dq_f}{dp_f} \\ \frac{d\beta}{dp_f} \end{bmatrix} = \frac{-1}{\mathrm{D}} \begin{bmatrix} \kappa_{\beta\beta} & p_b - \kappa_{q_f \beta} \\ p_b - \kappa_{\beta q_f} & \kappa_{q_f q_f} \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} \qquad \text{(A3),}$$

where $\mathrm{D} \equiv |\mathrm{K}| = \kappa_{\beta\beta} \cdot \kappa_{q_f q_f} - (p_b - \kappa_{\beta q_f})^2 > 0$ is the determinant of matrix K, and is greater than zero given that this matrix is negative definite, i.e. the profit maximization assumption.From (A3), it follows that $\frac{dq_f}{dp_f} = \mathrm{D}^{-1}(-\kappa_{\beta\beta}) < 0$, which proves Proposition 4. Further, notice that $\frac{d\beta}{dp_f} = \mathrm{D}^{-1}\left[-(p_b - \kappa_{\beta q_f})\right]$. This relationship can be usefully transformed into elasticities when one considers, like in the previous cost function, that there is symmetry in cross-elasticities (β, q_f), imposed by first-order conditions (7):

$$\kappa_{\beta q_f} \frac{q_f}{\kappa_\beta} = \epsilon_{\beta q_f} = \epsilon_{q_f \beta} = \kappa_{q_f \beta} \frac{\beta}{\kappa_{q_f} + p_f}.$$

Hence, using (A3) and the definition of these cross elasticities, it can be shown that:

$$\frac{d\beta}{dp_f} = (\mathrm{D} p_b)^{-1} (\epsilon_{\beta q_f} - 1) \qquad \text{(A4),}$$

which proves Proposition 5.

The effect of prices on total losses at the intermediary level is derived from the definition of total losses, $L_b = (1 - \beta) q_f$, from where it is derived:

$$\frac{dL_b}{dp_f} = \frac{dq_f}{dp_f}(1 - \beta) - \frac{d\beta}{dp_f} q_f = -\frac{\kappa_{\beta\beta}}{\mathrm{D}}(1 - \beta) + \frac{p_b - \kappa_{\beta q_f}}{\mathrm{D}} q_f.$$

The second expression relies on the comparative static results derived in (A3). Again, it can be conveniently divided by p_b, using first-order conditions (7) to show:

$$\frac{dL_b}{dp_f} = \frac{q_f}{\mathrm{D} p_b} \left[-\frac{(1-\beta)}{\beta} \epsilon_{\beta\beta} - \epsilon_{\beta q_f} + 1 \right] \qquad \text{(A5),}$$

which proves Proposition 6.

The comparative statics with respect to the selling price of the intermediary are again obtained by differentiating first order conditions, and using K matrix:

$$\begin{bmatrix} -\kappa_{q_f q_f} & p_b - \kappa_{q_f \beta} \\ p_b - \kappa_{\beta q_f} & -\kappa_{\beta\beta} \end{bmatrix} \begin{bmatrix} dq_f \\ d\beta \end{bmatrix} + \begin{bmatrix} \beta \\ q_f \end{bmatrix} dp_b = \begin{bmatrix} 0 \\ 0 \end{bmatrix}.$$

Again, inverting the second order conditions matrix and collecting terms results on the following:

$$\begin{bmatrix} \frac{dq_f}{dp_b} \\ \frac{d\beta}{dp_b} \end{bmatrix} = \begin{bmatrix} \frac{\kappa_{\beta\beta}\beta+(p_b-\kappa_{q_f\beta})q_f}{\mathrm{D}} \\ \frac{\kappa_{q_fq_f}q_f+(p_b-\kappa_{q_f\beta})\beta}{\mathrm{D}} \end{bmatrix} \qquad \text{(A6).}$$

A6 can be used to prove Proposition 7,

$$\frac{d(\beta q_f)}{dp_b} = \frac{dq_f}{dp_b}\beta + \frac{d\beta}{dp_b}q_f = \mathrm{D}^{-1}\left[\kappa_{\beta\beta}\beta^2 + 2\left(p_b - \kappa_{q_f\beta}\right)\beta q_f + \kappa_{q_fq_f}{q_f}^2\right] = \qquad \text{(A7),}$$

$$\mathrm{D}^{-1}\cdot\begin{bmatrix}\beta & q_f\end{bmatrix}\cdot\begin{bmatrix}\kappa_{\beta\beta} & p_b - \kappa_{q_f\beta} \\ p_b - \kappa_{\beta q_f} & \kappa_{q_fq_f}\end{bmatrix}\cdot\begin{bmatrix}\beta \\ q_f\end{bmatrix} > 0$$

which is unambiguously positive, because the square matrix in (A7), the negative of the adjoint of K, is positive definite given that K is negative definite.

The comparative statics of equilibrium of the intermediary with respect to changes in the selling price is given by:

$$\begin{bmatrix}-\kappa_{q_fq_f} & p_b - \kappa_{q_f\beta} \\ p_b - \kappa_{\beta q_f} & -\kappa_{\beta\beta}\end{bmatrix}\begin{bmatrix}dq_f \\ d\beta\end{bmatrix} + \begin{bmatrix}\beta \\ q_f\end{bmatrix}dp_b = \begin{bmatrix}0 \\ 0\end{bmatrix}.$$

Inverting the Hessian and collecting terms gives the following result:

$$\begin{bmatrix}\frac{dq}{dp_b} \\ \frac{d\beta}{dp_b}\end{bmatrix} = \frac{1}{\mathrm{D}}\begin{bmatrix}\kappa_{\beta\beta} & p_b - \kappa_{q_f\beta} \\ p_b - \kappa_{\beta q_f} & \kappa_{q_fq_f}\end{bmatrix}\begin{bmatrix}\beta \\ q_f\end{bmatrix}. \qquad \text{(A8).}$$

From (A8), one can derive the expression, $\frac{d\beta}{dp_b} = \mathrm{D}^{-1}\left((p_b - \kappa_{\beta q_f})\beta + \kappa_{q_fq_f}q_f\right)$, which can be transformed into elasticities, as before:

$$\frac{d\beta}{dp_b} = \frac{\beta}{p_b\mathrm{D}}\left(1 - \epsilon_{q_f\beta} + \epsilon_{q_fq_f}\right) \qquad \text{(A9),}$$

which proves Proposition 8.

To prove Proposition 9, notice that:

$$\frac{dL_b}{dp_b} = \frac{dq_f}{dp_b}(1-\beta) - \frac{d\beta}{dp_b}q_f = \frac{dq_f}{dp_b} - \frac{d(\beta q_f)}{dp_b} \qquad \text{(A10).}$$

The first element of the last expression can be obtained from (A8), $\frac{dq_f}{dp_b} = \mathrm{D}^{-1}\left(\kappa_{\beta\beta}\beta + (p_b - \kappa_{q_f\beta})q_f\right)$ or in elasticities:

$$\frac{dq_f}{dp_b} = \frac{q_f}{p_b\mathrm{D}}\left(\epsilon_{\beta\beta} + 1 - \epsilon_{q_f\beta}\right) \qquad \text{(A11).}$$

While the second part of the expression (A10) is presented in (A7), which can be transformed into elasticities:

$$\frac{d(\beta q_f)}{dp_b} = \beta\frac{q_f}{p_b\mathrm{D}}\left[\epsilon_{\beta\beta} + 2\left(1 - \epsilon_{q_f\beta}\right) + \epsilon_{q_fq_f}\right] \qquad \text{(A12),}$$

Hence, using expressions (A11) and (A12), it can be shown that:

$$\frac{dL_b}{dp_h} = \frac{q_f}{p_h\mathrm{D}}\left[(1-\beta)\left(\epsilon_{\beta\beta} + 1 - \epsilon_{q_f\beta}\right) - \beta\left(1 - \epsilon_{q_f\beta} + \epsilon_{q_fq_f}\right)\right] \qquad \text{(A13),}$$

Which is used to construct Proposition 9.

The buyer/consumer

Formally, the consumer problem may be stated as a standard constrained optimization problem:

$$\max_{q_c,z,l,k,f} U(f,l,z) + \mu_1\big[f - f(k,q_c)\big] + \mu_2\big[w(T-l-k) - p_b q_c - z\big]. \tag{A14).}$$

This problem has first-order conditions (assuming interior solutions):

$$U_f + \mu_1 = 0 \tag{A15}$$

$$U_l - \mu_2 w = 0 \tag{A16}$$

$$U_z - \mu_2 = 0 \tag{A17}$$

$$-\mu_1 f_k - \mu_2 w = 0 \tag{A18}$$

$$-\mu_1 f_{q_c} - \mu_2 p_b = 0 \tag{A19}$$

Using first-order conditions (A18) and (A19), it is easy to construct relationship (8), as shown in the text.

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