Rapid transformation of food systems in developing regions: Highlighting the role of agricultural research & innovations

Citation:

Reardon, Thomas; Echeverria, Ruben; Berdegué, Julio; Minten, Bart; Liverpool-Tasie, Saweda; Tschirley, David; Zilberman, David. 2018. Rapid transformation of food systems in developing regions: Highlighting the role of agricultural research & innovations. Agricultural Systems In press.

Publisher's DOI:

https://doi.org/10.1016/j.agsy.2018.01.022

Access through CIAT Research Online:

http://hdl.handle.net/10568/91201

Manuscript Details

Manuscript number	AGSY_2017_791_R1
Title	Rapid transformation of Food Systems in Developing Regions: highlighting the role of agricultural research
Article type	Research Paper

Abstract

Developing regions' food system has transformed rapidly in the past several decades. The food system is the dendritic cluster of R&D value chains, and the value chains linking input suppliers to farmers, and farmers upstream to wholesalers and processors midstream, to retailers then consumers downstream. We analyze the transformation in terms of these value chains' structure and conduct, and the effects of changes in those on its performance in terms of impacts on consumers and farmers, as well as the efficiency of and waste in the overall chain. We highlight the role of, and implications for agricultural research, viewed broadly as farm technology as well as research pertaining to all aspects of input and output value chains.

Keywords	value chains, food markets, food waste, food systems; input supply chains; agricultural research

Corresponding Author	thomas reardon
Corresponding Author's Institution	Michigan State University
Order of Authors	thomas reardon, Ruben Echeverria, Julio Berdegué, Bart Minten, Lenis Liverpool-Tasie, David Tschirley, David Zilberman

Suggested reviewers	Peter Matlon, Luc Christiaensen, David Dawe, Matty Demont, Stephen Vosti

Submission Files Included in this PDF

File Name [File Type]

agricultural systems - september 17 - reardon cover letter.pdf [Cover Letter]

agricultural systems - AGSY_2017_791 resubmission letter dec7.docx [Cover Letter]

Agricultural Systems - responses to reviews for 2017_791 Dec7.docx [Response to Reviewers]

Agricultural Systems - AGSY_2017_791 resubmitted Dec7 2017 without cover.docx [Revised Manuscript with Changes Marked]

Agricultural Systems - AGSY_2017_791 highlights.docx [Highlights]

Agricultural Systems - AGSY_2017_791 abstract.docx [Abstract]

Agricultural Systems - september 17 - reardon submission.pdf [Manuscript File]

To view all the submission files, including those not included in the PDF, click on the manuscript title on your EVISE Homepage, then click 'Download zip file'.

MICHIGAN STATE UNIVERSITY

September 17, 2017

College of Agriculture and Natural Resources

Department of Agricultural, Food, and Resource Economics

Justin S. Morrill Hall of Agriculture
Michigan State University
446 West Circle Drive, Room 202
East Lansing, MI

Office: 517-355-4563
Fax: 517-432-1800
afre@anr.msu.edu

Agricultural Systems Editor

Dear Editor,

Please find attached a manuscript for Agricultural Systems for the Special Issue: Agricultural research for rural prosperity: Rethinking the pathways. The title is Rapid transformation of Food Systems in Developing Regions: implications for agricultural research strategies. The authors are below.

Thomas Reardon, Michigan State University, USA; reardon@msu.edu
Ruben Echeverria, CIAT, Colombia
Julio Berdegué, FAO Regional Office for Latin America & the Caribbean, Chile
Bart Minten, IFPRI, Ethiopia
Saweda Liverpool-Tasie, Michigan State University USA
David Tschirley, Michigan State University, USA
David Zilberman, UC Berkeley

Thank you.

Sincerely,

Thomas Reardon

MICHIGAN STATE
UNIVERSITY

December 7, 2017

College of Agriculture and Natural Resources

Department of Agricultural, Food, and Resource Economics

Justin S. Morrill Hall of Agriculture
Michigan State University
446 West Circle Drive, Room 202
East Lansing, MI

Office: 517-355-4563
Fax: 517-432-1800
afre@anr.msu.edu

Agricultural Systems Editor

Dear Editor,

Please find the revision resubmitted of a manuscript for Agricultural Systems for the Special Issue: Agricultural research for rural prosperity: Rethinking the pathways. The new title is Rapid transformation of Food Systems in Developing Regions: highlighting the role of agricultural research. The authors remain the same as original submission.

Please note that we did not highlight the text where changes were made because we cut wordiness in the text substantially, usually per reviewer request to cut certain things as well, and thus cut 5,000 words without changing all the main points of the original manuscript, and added according to what reviewers suggested. We noted our responses and changes in a separate "response to reviewers" note uploaded.

Thank you.

Sincerely,

Thomas Reardon

Agricultural Systems AGSY_2017_791

Responses to each Reviewer under the points, in bold. December 2, 2017

Relevant to all reviews: Overall, we cut 5,000 words from the text to make it tighter.

Note that the text was not marked with the changes because we did such major cuts (5000 words) to the text while adding the material that we note below.

-Reviewer 1

- The authors are to be congratulated on having prepared a timely overview paper that succinctly synthesizes a wide set of existing studies of transformational change in food systems in Africa, Asia and Latin America. The comprehensive, multi-dimensional and cross-regional comparative framing make it a uniquely valuable contribution to the literature. Having said that, I believe that the manuscript can be significantly strengthened. In addition to a number of fairly minor modifications, additional work is required to ensure that the final paper maximizes it's contribution to the existing literature and so that it's contribution is more lasting. This can be done by broadening (and thereby updating its scope) to make it more forward looking and responsive to current debates.

I organize my brief recommendations around four broad points: (1) scope, (2) additional analyses, (3) definitions, (4) typos.

Scope

I strongly recommend that the authors incorporate consideration of a wider set of factors in their analysis, including:

(a) Environmental impacts of the transformational changes (on soil, water, biodiversity, climate change.) For example, pg 23, ln 16 , longer supply chains are not only exposed to climate change-related shocks, but they also contribute to a larger carbon foot print. Similarly, in section 5.3, pg 35 and after, some recognition of the environmental costs of technological changes associated with intensification on water, soil and biodiversity would help round out that discussion. Other examples can be cited.

    Response: We have added this to the performance/impacts section 6, so collected in one place under environment rubric.

(b) Roles and effects of changes in the finance system on transformations across segments of the food system supply chain. This discussion would fit best in section 2 that addresses the "dendritic" nature of the food system. Timely, affordable and adequate financial flows, after all, are the lubricant and enabler of each of the system's segments and thus require some discussion.

    Response: We have added finance to both section 2 and to conduct/organization/institutions changes in section 5.2.

(c) Nutritional consequences of the food system transformations. Changes in the output mix of the farm sector (e.g. pgs 13 and after), as well as rising consumption of processed foods have direct impacts on consumer health, including both malnutrition (lower nutrient dense diets) as well as obesity and diabetes. These negative impacts need to be at least referenced, and ways to mitigate these threats suggested. In the context of current global debates on nutrition, it is advised that a single reference to the non-communicable diseases (pg 47, lns 12-14) is grossly inadequate.

Response: Nutrition effects have been added to section 6 on impacts/performance.

(d) Distributional and equity consequences of the transformations in both input and output markets (impacts on small farmers and poor consumers). The paper too often uses an "average" construct to describe major trends. However, because the welfare impacts on both farmers and consumers from any single transformational element are often diametrically different for different income classes, these should be addressed briefly or at least recognized, with references to related literature. Thus on pg 6 ln 7, the meta conditioners should include both income growth and distribution And on pg 13 section (c) it would be appropriate to include best estimates of how expenditure patterns vary across income groups, especially the lowest and highest deciles or quintile in both rural and urban areas. Similarly, on pg 21 lns 18-22, and pg 22, ln 8.

Response: We especially add on the distributional/exclusion issues in section 6 on performance. In some other places, such as consumption changes, we highlight some surprises from recent empirical evidence showing diet transformation is widely distributed across income groups.

While it would be unreasonable, and probably impractical, for the authors to go into great depth in each of these areas, at least some (preferably cited) reference to each of areas would demonstrate awareness of the issues and underline key functional relationships.

It is also strongly recommended that the authors help frame and prioritize future research in these areas in their final section 7 (pg 49).

Response: we have added in the implications section.

Additional analyses

Pg 9, ln 18 and after. Provide best available estimates of income elasticities of demand by region and food group.

Response: Done.

Pg 11, lns 12-18. Provide possible explanations of anomalous results for West Africa regarding the increasing share of expenditure on grains. My assumption is that it reflects a shift from coarse grains to rice, but the authors should comment.

Response: Agreed, added.

Pg 14, lns 13-15. Recognize the rapid growth in rice production (and consumption) in Africa over the past three decades.

Response: Added.

Pg 16, ln 17 and after. Expand discussion of productivity change beoynd production to include wider set of food system segments.

Response: We put this into the performance section 6 and conclusions section 7.

Pg 18, lns 13-15. If data is available, show how trends in consumption of imported foods differ between coastal and inland urban areas on Africa.

Response: While this is interesting in itself, we think that this detail is not essential to our focus and three-region breadth.

Pg 6, ln 21 and after, Pg 29, ln 18 and elsewhere. Need a much more substantial discussion of the specific policy and regulatory changes that have occurred in African, Asian and Latin American countries over time, and how these have enabled the multiple food system transformations. This is one of the weakest aspects of the current draft.

Response: All the reviews told us to cut the text substantially, saving on space wherever something is not essential to the basics of transformation and the implications for the research agenda. That is why we have kept the drivers of transformation, as opposed to the path of structure, conduct, and performance points, lean. We feel that we have already provided the lean points on the policy drivers, with respect to liberalization of internal and external trade and FDI, and privatization. Those are the essential drivers of the structure change to present. We have added some on the regulatory changes, in particular food safety and nutritional composition that will gradually become more substantial in the future.

Pg 22 section (c) and elsewhere. Need greater discussion of the changing dynamics and potential of urban and peri-urban agriculture within the context of food systems transformation. There is only a single reference (pg 43, lns 6-7).

Response: We are striving to keep the discussion as lean as possible. Urban agriculture per se is both a tiny share of total agriculture now, and as a category does not change our basic structural discussion. Peri-urban agriculture is rural, just near the city, and we have added a qualifier on longer supply chains (the main trend now and for the next several decades in developing countries) to note that horticulture at present takes place in relatively short chains (but former periurban products, like chicken and fruit and fish, are produced at increasing distances with transport and storage technologies improving.)

Pgs 31-33, section 5.1. Current draft places too much emphasis on imported technologies and largely ignores the wide number of successful new agricultural production technologies that have been developed by R&D conducted within the regions, including Africa.

> **Response: We have supplied examples from each of the three regions and a general point in section 5.**

Pg 34, lns 4-8. Need to acknowledge frequent negative impacts of consolidation in wholesale and retail markets serving urban areas in general and supermarkets in particular on small farmers in the absence of major institutional changes at the farm community level.

> **Response: We have added more on issue and occurrence of exclusion in the face of concentration in the supply chain, in section 6 on performance.**

Pgs 36-42. The flow of the paper seems to break here by departing from comparative analyses within the three regions to a review of anecdotal experiences from OECD (developed) country food and agriculture systems. Paper should retain its focus on a review of empirical evidence in Africa, Asia and L. America to make its points.

> **Response: Our focus is made more emphatically on developing regions examples, but we believe it is valuable and reinforces our points to show parallelism between the currently developed countries' experience (when they were developing countries) and currently developing countries. This highlights the basic system phenomenon driving the changes, showing the specific context does not alter the logic of the sequence of change and the economic reasons for it.**

Pg 46, lns 4-10. The tautological argument is weak and unconvincing. Small farmers don't necessarily benefit in the short and medium terms by increased volume of production. The Asian GR demonstrated this due to distorted input and land tenure systems, etc. And with modern procurement systems demanding more timely, bulk and higher and more consistent quality of production, small farmers can also lose out in the short-term unless institutional innovations in farmer organizations are implemented.

> **Response: These qualifications are noted in the part on what benefit and what challenge the volume increase per se has on farmers. Then we discuss quality requirements as an additional challenge. All of this is now more fully treated in the performance and impacts section, section 6.**

<u>Definitions</u>

Pg 7, ln 18 and after. Need to define what constitutes an "urban" area more rigorously and across regions, taking into consideration, primary, secondary and tertiary cities and towns. It is impossible to understand the results presented without a clear definition of size and structure. A footnote would work.

> **Response: We added this in section 3.2. where urban shares are first discussed.**

Pg 21, ln 1 and after. Define “rural” markets.

Response: We added this in 4.3.2.b. where rural markets are first discussed.

Pg 21, ln 10. Similarly, need for a definition of “middle class” across regions.

Response: We added this in the diet change section.

Typos, lack of clarity

Response: We addressed these.

Pg 1, lns 14 and 21. The first point includes the second.

Pg 4, ln 3. The word “that” is missing.

Pg 19, section 4.2.2. 3rd supply side impact is missing. List reads 1st, 2nd, 4th.

Pg 22, ln 15. Should read: “…supermarkets, urban traders….

Pg 31, lns 20-21. Should read: “…Key innovations in agricultural production technology….as well as in processing…”

Pg 45, ln 8. Sentence not clear.

Pg 45, ln 10. Delete word “study”.

-Reviewer 2

This is a fantastic paper that brings together in one place a detailed set of evidence analysis about the recent and on-going transformations in global food systems. I particularly enjoyed the way the paper illustrated the interconnectivity of technical and institutional innovations in different but obviously related value chain elements. The recommendations for the research responses needed by NARS and IARCs are clear and even apparently simple, but have fundamental implications for historically patterned research capabilities and priorities. Of the many things that I found pleasing was the demolishing of the food loss / waste myth (Martin Greeley’s 1980’s study on grain losses and the save grain campaign in India is an other (under used) example of debunking of this myth).

Response: Thanks, this puts wind in our sails! And we added Greeley.

On the other side of the leger, I wonder if something further could be said of the political economy of the transformation processes that are going. The paper very clear states, towards the end, that it is the private sector that is in the driving seat – both large agribusiness firms and MSMEs. I think this is correct. However, what does this private sector led change really mean for the directionality of the change process? The paper suggests that it has been positive for small holder farmers and poorer urban consumers at the aggregate level. However as Kaplinsky and other have noted the development of value chains tends to concentrate power at the expense of primary producers. I guess my point here is that the performance of modern food systems needs to consider the way inclusion, nutrition and environmental sustainability performance is tracking. Should public policy simply take a lazire fair approach and let the private sector proceed unshackled? Or is this an approaching era where public policy needs to intervene once more to ensure that that directionality of performance is inline with, for example, the SDGs. What does this say about the governance of food system transformation going forward? Might it start to look like self-regulation by the private sector on issues such as sustainability and ethical business practice (which there is some evidence of)? What might the role of the public purse be in this context? As a kind of related aside, a recent world bank publication, the Innovation Paradox, makes the point that MSEM in developing countries don't have the innovation capacity to absorb technical innovations from else where, therefore technology catch up is slower than expected. In the food sector this might mean that sustainability facing innovations that are popping up in modern food systems might be slow to diffuse in transitioning systems unless public investments are made in building the innovation capacity of MSME. Just a thought!

Response: To reflect this, we build into section 6 on performance the issues of producer exclusion (both farmers and SMEs), and reference calls to address that, and nutrition/obesity issues on the consumption side, and reference calls for some type of regulation.

Finally, a selfish point (as a semi-aridist). The paper doesn't mention the course grains, sorghum and millets. I guess your analysis suggest that these will simply be replaced by maize, wheat and rice and drought tolerance etc can be improved in these for more arid areas, even in the face of climate change. What would that imply for the performance of the food system in arid regions where the sorghums and millets have been historically important? Are pulses a special case in India??

Response: In the section on shifts in demand we have added the striking case of the rise of processed millet/sorghum in prepared dishes marketed for example in Senegal and Nigeria, a riposte for coarse grains in the convenience battle. We also added that in the SME proliferation part in the midstream discussion.

In conclusion, a fantastic paper that I really enjoyed with perhaps some options for minor tweaks.

Response: we are grateful.

-Reviewer 3

-

I really enjoyed reading this paper for its informative narrative on changes in VCs. It explains how VCs have transformed in history (hence, the many references to USA, Europe). It does also contain enough reference to developing countries to be relevant to the SI, but there the linkage to poverty reduction can be strengthened. I'd conclude that VC development can support small farmers, but most likely those who have the agency and resources to hop on board (hence, not likely those in a poverty trap) - correct?

Response: Agreed, and added/emphasized in/ to effects/performance part (where we note "actor incomes" but have made it fuller link to poverty reduction and poverty traps in the second paragraph of section 6 which treated your point but can be filled out to emphasize.

It paper needs a hard edit and some tighter focusing.

Response: Hard-edited and cut substantially with (relative) focusing (although the terrain is broad per TOR).

Further points include:

- Title – Rapid transformation of Food Systems in Developing Regions: where <u>agricultural research has</u> and will contribute

  Response: changed to this better title.

- Need an abstract

  Response: Added.

- The 'five interlinked transformations' are a great framing and are conducive to research support … the paper needs to tick off on where such support has happened. Question 2 promises to document the past contribution of research.

  Response: We have added in the introduction that research has especially aided the upstream transformation, in particular for grain yields and key inputs to that end. The further path of research will need to be quality and differentiation of output and midstream/downstream performance improvement, as well as system-wide issues like energy and resilience.

- The early admission that "argumentation will need to rely on causal association by inference and cases" weakens the paper and the case for research contribution to post-farm VC interventions. This paper needs to provide the case.

  Response: Revised the wording. The fact is we did as much as empirical base will allow. We had meant that the direct link, say of a specific technology breakthrough and a system transformation, is not a tight link but a general correlation.

- Or maybe make the argument that action research in VCs is essential because "evidence on the transformation of the off-farm segments of the food system is relatively limited and emerging and incomplete"

- Don't cross reference special issue papers other than using normal referencing

  Response: Done.

- Use of first person to mix represent five interlinked transformations of authors and research community. Probably better to use 3rd person.

  Response: done.

- Section 2, while helpful, can be removed to cut length; simply use a ref.

  Response: There is no reference for this because to our knowledge there is no exposition of this point in the literature. But we cut it down significantly.

- Section 4: Structural change in the food system, again is very interesting but can be cut in length significantly by stating the main trends (as per the sub-headings) and referring to references.

Response: Revised according to this point.

- Section 5 is the key to the paper in the context of the SI. This section needs to be less explanatory and use more referenced evidence.

  Response: Revised according to this point.

- Can remove the internal prefaces to sections (e.g. Section 5.3) "In this section we discuss the technology changes that occurred as the food system transformation occurred, and thus by extension the impact of technology research in IARCS and NARS and private companies on that transformation. We start with upstream, then look downstream. Within each, we start with commoditization-facilitation technologies (that get costs down), and then go to product differentiation-facilitation technologies (that help produce other attributes like quality and safety)."

Response: done.

- Section 7 is very important for the SI. But it is too much a rehash summary of preceding sections and not enough in concluding what next for R&D, supported by references.

  Response: we removed the summary and beefed up the implications discussion.

Rapid transformation of Food Systems in Developing Regions: Highlighting the role of agricultural research

1. Introduction

The “food system” (the dendritic cluster of R&D value chains and the value chains linking input suppliers to farmers, and farmers upstream to wholesalers and processors midstream, to retailers then consumers downstream) has transformed enormously over the past 50 years. The most rapid change occurred only in the past 25 years. It shifted from being a traditional system to a mix of transitional and modern. From a historical perspective, the transformation was abrupt, not gradual. Reardon and Timmer (2014), illustrating with Asian evidence, explain the drivers as a confluence of “five interlinked transformations:” (1) Downstream demand side change “pulling” system transformation: (a) urbanization; (b) diet change; (2) Midstream/downstream change, “intermediating” system transformation: (c) change in retail, wholesale, logistics, and processing; (3) Upstream change, “feeding” system transformation: (d) intensification of farming; (e) farm input supply chain change.

Our paper extends the above work by comparing transformations, extending analysis to Africa and Latin America and updating analysis of Asia. We also extend the analysis to the role of agricultural research as a determinant of food system transformation. Here “agricultural research” includes both research on the inputs and farm segment (breeding, input design, agronomic practices, and so on) and research on the off-farm post-farm segments (on technologies and organization of processing, packaging, logistics, wholesale, retail).

We address four questions:

(1) How are food systems transforming?

(2) How have research and non-research factors (urbanization, income growth, diet change, policies) influenced food system transformation?

(3) What have been the effects of transformation on consumers and on small and medium farmers, as well as on system performance measures such as supply of affordable and safe and quality food, and efficiency and waste in the system? By chain-rule logical extension, we thus examine how research affects consumers and farmers via the "pathways" of food system transformation.

(4) What are the implications of the transformation for agricultural research strategies?

Our findings lead to the two main messages of the paper.

First, the research community, hitherto mainly focused on the farm segment of the system, needs to take into account the entire food system and its transformation in their research strategies. This will determine whether innovations in farm technology and products lead to profitable marketed output by farmers. Increasingly, the urban market, the food industry firms that mediate access to the urban market, input supply chains, and agribusiness firms that determine the development of input supply chains, set the market incentives and conditions for the affordability and profitability of new farm technologies, and thus their adoption.

Second, the research community needs to understand and act on the importance of processing and logistics and wholesale (of outputs and inputs) in the food system, and research on these off-farm components of the food system. Research on and productivity of technologies for input manufacture and output processing, packaging, logistics, and commerce have equal weight in the performance of the food system relative to the farm sector. Investment in research and development (R&D) for these off-farm segments needs a much higher profile in the context of the transformed food system where off-farm segments occupy 40-70% of value added and costs of food.

To address the research questions we face two challenges. First, unlike other pathways of the impacts of research on farmers and consumers, such as breeding research on farm yields, it is particularly complex to examine research impacts on food systems and thence on farmers and consumers. Research is just one of the conditioners of the transformation and its impacts. The emphasis must be put on discussing the transformation itself and positing impacts of research in combination with other factors (such as urbanization). Second, as food system transformation in these regions is relatively recent, and the great majority of studies have been on the farm sector, empirical evidence on the transformation of the off-farm segments of the food system is only emerging and incomplete. We do our best to survey what is available.

The paper proceeds as follows. Section 2 lays out a conceptual framework. Section 3 explores "downstream" drivers of food system transformation – urbanization, income growth, diet change, infrastructure investments, and policies. Section 4 examines trends in the transformation of the structure, and Section 5, in its conduct (including technology change). Section 6 discusses emerging evidence of the system's performance. Section 7 presents implications for agricultural R&D strategies.

2. The Food System as Dendritic

The food system can be thought of as "dendritic," linking R&D, finance, input, and output supply chains, as follows.

The first and "core" supply chain is the output value chain. An example from the rice system is an output value chain composed of rice farmers producing paddy, which is collected by rural wholesalers or transporters and taken to mills where it is de-husked and polished. The rice is taken by wholesalers to urban wholesale markets and then to retailers.

The second and upstream "feeder" supply chains are the farm input supply chains, such as seed, fertilizer, farm equipment, labor, and arable land. These in turn are fed by input supply chains further upstream, such as the supply chain from phosphate mines to phosphoric acid plants to phosphate fertilizer factories.

The third and downstream "feeder" supply chains are those supplying inputs to the post-farmgate segments, in a sense "laterally." An example is the truck and fuel supply chains to rice wholesalers.

The fourth "pan-system feeder" supply chain is that supplying finance into every segment of every chain in the dendritic system. This can be formal or informal credit supply chains, or the most common in developing countries, own finance from retained earnings.

The fifth "feeder" supply chain is a broad set of public assets apart from agricultural research institutions such as infrastructure, police protection, and court systems for contract enforcement.

The sixth set of "feeders" is the R&D supply chains which supply technology and product innovations. For instance, companies and the National Agricultural Research System (NARS) and the International Agricultural Research Centers (IARCs) breed new seeds which feed seed supply chains which supply paddy farms. Moreover, universities and companies form public-private partnerships that involve an emerging "educational-industrial complex" (Zilberman et al. 2012) where innovation starts at university research centers and ideas are then further developed either by applied research centers (like the CGIAR and NARS) or by private sector entities (startups, small companies, and major corporations). The innovations in agricultural technology, food processing, packaging, logistics, and so on that are supplied by R&D value chains are often powerful drivers of change in the other parts of the system.

The segments in each of the above value chains, and the six value chains themselves, are intertwined in "intersectoral (or intersegment) linkages." An increase in demand or supply from one segment "induces" investment in another segment or chain (Hirschman, 1958). The induced investment can be in physical capital or hiring labor, but it can also be in the formation of an R&D supply chain: innovators (public or private) cum entrepreneurs design and market new technologies or new products to meet demand in other value chains. For example, if supermarket chains demand shelf-stability in vegetable varieties they contract to procure, innovators can endogenously implement a vegetable breeding innovation to breed a shelf stable variety, as derived demand from farmers wishing to supply the supermarket chain.

But seen from the perspective of a given food system, there can be exogenous R&D "investment" that is not induced by factor scarcity or attribute demand in that food system. The R&D supply chain may endogenously arise in another context (another country, another product, etc.) and then present a technological innovation "exogenously" to the given food system. An example is the creation and manufacture of extruders for feed processing in the US. It might then be transferred to Bangladeshi feed mills using imported machines embodying this innovation. This would give the importer a competitive advantage and perhaps induce concentration in the feed supply chain in Bangladesh.

3. Transformation of Food Systems: downstream and context drivers

3.1. Meta conditioners: Income growth, policy liberalization, and infrastructure investment

There are three “meta conditioners” that encouraged and facilitated nearly all the transformations we discuss.

First, growth in income and population in the three regions was crucial as a pull factor. Incomes rose, especially starting in the 1980s in Latin America and Asia outside the transition countries (China, Vietnam, and India) and 1990s in Africa and the Asian transition countries. Income growth, along with increasing opportunity cost of time as women worked outside the home in urban and rural areas, led to diet and shopping changes discussed below.

Second, policy liberalization and privatization occurred during the 1980s and 1990s (from the transitions in China and Vietnam, to the de-reservations in India, to structural adjustment programs in all three regions). This led to a minimization of governments’ direct role in food systems. It also increased private sector MSMEs (micro, small, and medium enterprises) that stepped into the void left by parastatals, with MSME proliferation encouraged by the expanding urban markets. The policy changes also led to entry of large-scale domestic and foreign firms such as processors and supermarket and fast food chains, as well as large input firms. The massive ingress of foreign companies was abetted by liberalization of the once-ubiquitous foreign direct investment (FDI) regulations in the 1980s-2000s.

Third, governments instituted large infrastructure programs in Asia and Latin America in the 1980s and 1990s and in some African countries (e.g. Ethiopia, Minten et al., 2014b) in the early 2000’s. This reduced transaction costs and formed the foundation for food supply chain development from rural areas to the burgeoning cities and towns.

3.2. Urbanization

In a traditional situation, the urban share of the population is low. Supply chains are mainly short and local, serving villages and nearby towns. But as urbanization occurs, supply chains must stretch out from the cities and grow longer as the city needs a larger and larger catchment area to feed itself. Some fresh produce and chickens and aquaculture may be produced in peri-urban areas (rural areas near towns), but less perishable products such as grains and roots/tubers are produced far from cities and brought in. Even horticulture products and chicken and milk are increasingly produced far from cities as processing - such as vegetable freezing and ultra-high temperature milk processing - are located far from cities where production costs are lower (Reardon, 2015).

Urbanization has indeed been occurring, and quickly, in all three of the regions. Latin America's urbanization was earliest, with the urban share roughly 40% in 1950, 55% in 1970, 65% by 1990, and 75% by 2010 (UN, 2014). Asia's urban share was only 20% in 1960, rising to 45% on average by 2011, and projected to 60% by 2025 (UN, 2011). Africa had a 40% urban population share by 2011, up from 24% in 1970 and projected to average 48% by 2030 (UN, 2011). The latter figure masks heterogeneity between countries; for instance, the urban share in Nigeria is 50% by 2015 (Bloch et al., 2015).

Moreover, the urban food market is in fact the majority food market on average in the three regions. This is because urban areas have higher incomes than rural areas (e.g., in ESA, Eastern and Southern Africa not including South Africa, urban income per capita is double that of rural; Tschirley et al., 2015), enough so to overwhelm the negative relation of income and overall food budget share noted by Engel's Law. In an Asian study of Bangladesh, Nepal, Indonesia, and Vietnam, Reardon et al. (2014b) show that while 38% of the population is urban, 53% of food consumption is urban. Even in the poorest region, ESA, 26% of the population is urban but cities consume 48% of food produced and sold (Dolislager et al., 2015).

To feed the cities, rural-urban supply chains have grown rapidly. Haggblade (2011) estimates this growth at 600-800% over three decades for Africa; Reardon and Timmer (2014) have it at roughly 1000% in Southeast Asia in the same period.

3.3. Diet change

3.3.1. Rise in the share of non-cereals

As incomes rise, "Bennett's Law" (Bennett, 1954) predicts a shift toward a higher proportion of non-staples in the diet. At a system level, this means that with development (which we roughly proxy by GDP per capita), one expects disproportionate growth of the supply chains of non-staples such as vegetables and fruit, meat and fish, dairy, and edible oils. Table 1 shows this with macro data from FAOSTAT for 1970 to 2013 with shares of tons of consumption-by-disappearance.

For Africa, the share of cereals inched down from 28% to 26%, roots/tubers stayed stable at around 20%, and non-staples rose from 50 to 55%. There was however some composition change in cereals consumption especially in West Africa toward rice, discussed below.

For Asia, the non-staples rise was more dramatic: cereals were 40% in 1970, inched down to 37% by 1990, and then dropped to only 24% by 2013. Timmer et al. (2010) use macro data on rice to show that in most Asian countries there has been a stagnant trend in rice consumption per capita, and even in some cases a gradual decline. Roots/tubers moved from 15% to only 3% over the period. By contrast, the striking winner in the diet was non-staples, soaring from 46% to 74%.

Latin American diet composition changed less during the period compared to the other two regions. This could be because a considerable part of Latin America's rapid development occurred in the 1960s-1970s, two decades earlier than most of Africa and Asia. Even by 1970 staples were only 30% of Latin American consumption, and that share had only dropped to 24% by 2013, and non-staples to 76%, like Asia.

Recent micro level survey data on household food expenditures corroborate the above macro figures.

For Asia, Reardon et al. (2014b) analyzed household survey data (LSMS) from 2010 and found that that for South Asia (Nepal and Bangladesh) and Southeast Asia (Indonesia and Vietnam), the share of cereals (mainly rice) in the food budget in value terms was about 26% for urban and 37% for rural households on average. Interestingly, the poorest tercile was only a little higher: 37% for urban and 47% for rural areas. Despite average income differences between the South Asian sample and the Southeast Asian sample, they found the shares of cereals in urban food budgets were similar (29% in South Asia and 23% in Southeast Asia). Meat and fish averaged 30% of the urban budget – itself equal to the grain share. Horticulture products averaged 15%. Together meat/fish and horticulture average 45%, more than grains all together. Another study showed similar results for India: Indiastat (2010) showed that the share of cereal in the urban diet (in value terms) dropped from 36% in 1972 to 23% in 2006, and in the rural diet, from 56% to 32%.

It may come as a surprise that African findings from LSMS analysis do not differ sharply from Asia's. For ESA urban and rural areas, Dolislager et al. (2015) found for Malawi, Tanzania, Uganda, and Zambia, that the share of grains (mainly maize) in urban food expenditure (in value terms) was 34%, and rural, 39%. The share of non-grains in urban food expenditure was 66%, and rural, 61%. As in Asia, they found the patterns for the poor stratum were not that different from the other strata.

For West Africa urban areas, Hollinger and Staatz (2015) analyzed data from urban food expenditure studies. Where the main staples are grains alone (Burkina Faso, Mali, and Senegal), they found that the share of grains in diets in value terms increased some over several decades: from 33 to 38%, and 62% of expenditure is on non-grains. Animal products and fish are the foremost items in this set: in the 2000s they formed a quarter of the total. Fruits/vegetables average another 12% (compare that with 16% in Asia and the US). Meat plus horticulture products equal grain expenditure in the urban Sahel. They found that for the countries where grains plus roots/tubers are the staples (Cote d'Ivoire, Ghana, and Nigeria), the share of grains dropped from 27 to 23% and tubers/roots rose from 14 to 17% over the 1990s to the 2000s. The share of non-staples (neither grains nor roots/tubers) was about 60%. Again meat/fish was found to be 21% of expenditure, and horticulture products, 17%: together (38%) they have nearly the share of staples (grains and roots/tubers), 40%.

3.3.2. Shift of the diet toward (purchased) processed products

Research in the 1980s-1990s examined the incipience of processed food purchase in developing regions, driven by a new era of income increases and emerging urbanization and the rise of rural nonfarm employment. Processed food began to be sought as a time-saver for women whose opportunity cost of time increased as they entered the labor force outside the home in urban and rural areas, in Latin America (e.g., Amat y Leon and Curonisy, 1981, Peru); Asia (e.g., Senauer et al., 1986, Sri Lanka); and Africa (e.g., Bricas and Muchnik, 1985 for West Africa; Kennedy and Reardon, 1994 for East Africa).

There has been a revival of interest in processed foods in developing regions in the 2000s. This occurred with the confluence of (1) urbanization and increased incomes; (2) easing of import of processed foods; (3) FDI and domestic investment in processing following liberalization and privatization.

In Africa, processed foods have penetrated both rural and urban markets. In the ESA study of Tschirley et al. (2015), 56% of urban household, and 29% of rural household food expenditures (in value terms) went to processed foods. Some half to two-thirds of processed foods are low-processed, like packaged flour or noodles and bread. These are usually domestic products and time-savers for women. More processed packaged foods are usually a mix of domestic products and imports. For Nigeria, Liverpool-Tasie et al. (2017) found that while imported processed goods dominate in numbers of types of products, they are a minority in retail volume terms. Of course, a number of these products depend at least partially on imported raw materials such as flavorings, wheat, and milk powder.

In Asia, Pingali (2006) noted a “Westernization” of diets with packaged convenience foods emerging. Reardon et al. (2014b) (for the Asian countries noted op cit.) found that urban households dedicate 73% of food expenditures to processed foods, and rural households, 60%.

Surprisingly, the penetration of processed food did not differ much over income terciles in the African and Asian consumption analyses. Women in poorer and richer households are pressed for time working out of the home in rural nonfarm employment and urban jobs, and the quest for convenience in processed foods instead of laborious home processing characterizes both.

3.3.3. Shift of the Product Composition among grains

First, the surge in demand for livestock products has translated into the precipitous rise of demand for maize as a feed grain. A striking example is in China: maize (mainly for feed) had been half of the tonnage of rice in 1993 but by 2013 overtook rice (Zheng, 2013). In Bangladesh, aquaculture grew 25-fold in three decades (nearly all for the domestic market), spurring a massive rise in the feed industry and demand for maize and other feed grains (Hernández et al., 2017). Liverpool-Tasie et al. (2016) found in Nigeria that the maize-based feed industry grew 600% in the past decades as derived demand from the booming aquaculture and chicken sectors.

Second, the rise of demand for convenience foods by consumers has as a derived demand a rapid rise in wheat and rice. In Asian areas where rice traditionally reigned, wheat has made inroads in the form of noodles and bread (Senauer et al. 1986, for Sri Lanka; Pingali, 2006, for Asia overall). Timmer (2015) shows for Southeast Asia that wheat imports rose from 1 million tons in 1961 to 13 million by 2010, and wheat consumption from 2.8% to 11.5% that of rice.

In West Africa where millet and sorghum and tubers are the traditional staples, rice and wheat have rapidly increased with the drivers noted above (Reardon, 1993). While rice doubled in tons of domestic production in ECOWAS over 1987 to 2009, domestic rice output stayed at about 55-60% of self-sufficiency, and imports of cereals (mainly rice) soared from 1 billion to 5 billion dollars in those two decades (Hollinger and Staatz, 2015). There has been a recent surge in commercialization of prepared and packaged millet dishes in rural areas so coarse grains may be making a significant convenience riposte.

In East Africa, the rise of wheat consumption has also been driven by convenience food demand (Kennedy and Reardon, 1994). Wheat consumption in West Africa has also started to rise not just via the half century old luxury of bread for the middle class, but now as cheap fast noodles and bread and bean sandwiches for the poor. An example is the rapid spread of the Indonesian multinational Indofood's "indomie", a packaged (wheat) ramen noodle, produced by Indofood FDI in Nigeria (cooked often with egg, and thus a fillip to egg consumption) (Liverpool-Tasie et al., 2016b).

Third, in a number of countries there is a shift toward higher quality grains, such as finer rice in Bangladesh. In Ethiopia, there is a shift away from the cheap red teff to the more expensive and preferred white teff. This increasing shift in intra-cereal demand drives changes in the portfolio of farmers as well as changes in the milling sector (Minten et al., 2013, 2016).

4. Transformation of food systems – focus on structure

4.1. Stages of structural change

There has been a lot of variation in the timing of take-off and speed of transformation of food systems across products, regions, countries within regions, and zones within countries. In general the transformation is over three stages of structure and conduct change.

(a) The least advanced stage is the "traditional" system. This tends to be spatially short ("local") and fragmented in structure, using technologies with little capital and much labor, with no contracts or formal standards, and spot markets linking all segments.

(b) The next stage is the "transitional." It is spatially long (as cities grow and their catchment area is larger and larger) but still fragmented. Chain actors use a mix of labor-intensive and capital-intensive technologies. There are emerging public standards of quality. But still spot market relations dominate.

(c) The most advanced stage is "modern." It is usually spatially long. But it is consolidating in various segments (such as in retail, the rise of supermarkets). There is also some "disintermediation" such as supermarkets buying directly from processors, or urban wholesalers directly from farmers. Private standards are emerging, and some use of contracts. Capital intensification is common as the modern stage tends to coincide with higher wages in the economy. More quality and safety control are demanded by the food industry.

There have been waves of diffusion of food system transformation over space and products in the developing regions.

The spatial waves are as follows (Reardon and Timmer, 2012).

(a) The first wave included East Asia outside China (such as South Korea) and South America such as Brazil, with transformation taking off in the 1980s.

(b) The second wave was in Mexico and Central America and in parts of South America (such as Colombia, Chile), Southeast Asia outside "transition" countries, and South Africa (with the take-off starting in the 1990s).

(c) The third wave, taking off mainly in the 2000s, includes the "transition" countries, China, Vietnam, and India, and South American countries "catching up" such as Peru and Bolivia.

(e) The fourth wave, in the 2000s, includes parts of Africa especially in southern (Zambia) and eastern Africa (Kenya) and emerging in West Africa such as in Nigeria, Ghana, and Senegal.

The product waves are as follows. The grain value chains transform earliest, animal products next, and fresh fruits and vegetables last. (These waves are similar to the pattern of diffusion of change in Europe and US food systems earlier.)

4.2. **Dimensions of structural change**

4.2.1. Expansion

Food volumes grew a lot from 1970 to now with the steepest increase from 1990 to 2013 (the latest year in FAOSTAT). This pattern roughly tracks the path of "economic development" or average income growth. Table 1 shows "food supply quantities" from FAO food balance sheets for 1970, 1990, and 2013. These are measures of "domestic consumption by disappearance" per capita, calculated starting with aggregate production, adding imports, and deducting disposal of the output (exports, waste, storage for the next year, and use as seed). We then use their population data to derive aggregate consumption by disappearance per region. This is a rough measure as it is only in physical terms, not value or nutrition terms. A physical measure probably underestimates growth in value terms as non-staples and processed foods, which grew the fastest, have higher prices on average than grains or roots/tubers. But our goal here is not fine precision but orders of magnitude and key trends. Several points emerge.

First, in 43 years, the total "food system" in these three regions grew from 1.3 to 5 billion tons, 4-fold, faster than population grew (from 2.6 to 6.5 billion, 2.5 fold). Interestingly, the trends did not differ much over the three regions. Africa's food volume expanded 1.8 times in the first two decades and then 2.1 times in the following 25 years, hence 3.8 times over 43 years. Asia's total food supply rose 1.8 times in the first 20 years and then 2.1 times in the next 25 years, for overall growth of 3.8 times. Latin America's rose 1.7 times in the first 20 years and then 1.7 times in the next 25 years, for overall growth of 2.8 times.

Mirroring demand changes, output per category grew overall, but with relative gains for non-staples over the four decades – in Africa, 340% in cereals volume, 400% in non-staples; in Asia, 220% in cereals, 590% in non-staples; in Latin America, 230% in cereals, and 300% in non-staples.

Second, imports as a share of food supply (net of exports) have risen, but are still minor. In Africa, tons of imports rose 11 times over the 43 years – from 7% to 15% to 21% of consumption by disappearance. In Asia, they rose 7 times and went from 9% to 13% to 18% of total consumed tons. In Latin America, they rose 7 times, and went from 3% to 6% to 9% of consumption. Import growth occurred steadily over the whole half century; it was in the policy debate in Africa in the 1980s/1990s (see Reardon, 1993) and has continued in the debate in the 2000s (African Development Bank, 2016).

Third, agricultural exports, while often important in policy debates, are small compared with the domestic food system. In Africa, these reached 7% of the level of domestic consumption; in Asia, 10%; in Latin America, 22%. It was especially in Latin America that exports rose in the well-known story of its agricultural export success in the globalization period.

4.2.2. Elongation

(a) Growth of rural to urban food supply chains

When the urban share was low, supply chains were short, with farmers feeding themselves and local villages and towns. As the urban share rose, and the cities grew, supply chains stretched further and further to fulfill the enormous needs of the cities. As domestic supply chains surge to feed cities, several points stand out.

First, seen from the countryside, most food goes to cities. As noted above, roughly 50-75% of domestic food supply now goes to cities; in the 1970s it was but 20-30% depending on the region. Even in the least urbanized and poorest region, ESA, 46% of cereal consumption (home-consumed by farmers and purchased by rural and urban households) is consumed in urban areas;

61% of purchases of cereal, 52% of fruit and vegetables, 58% of meat and fish, and 63% of edible oils are consumed in urban areas (Reardon et al., 2014d).

Second, the product categories output growth plus the rise in the share of urban consumption in total national consumption both noted above together yield the result that one can double or triple the product category volume growth rates to get a rough idea of how much the volume of rural-to-urban supply chains increased over 45 years. For instance, for Africa, this means that non-staple rural-urban supply chains increased about 800 to 1000% (depending on the sub region). That figure is about 1800% for non-staples in Asia. These enormous climbs represent a major investment by actors along the supply chain from farmers to urban retailers and wholesalers.

(b) Growth of Rural-to-rural and urban-to-rural supply chains

Even rural consumer markets are developing fast.

First, in Africa over three decades, rural population grew from 0.37 billion in 1970 to 1.05 billion in 2011 (UN, 2011); in Asia, from 2.1 billion in 1970 to 4.2 billion in 2011. The increase in the rural market in value terms is greater than population growth shows, for in many areas rural incomes have grown over several decades, albeit with regional variation. Even in the poorest regions, a rural middle class has emerged; Tschirley et al. (2015) demonstrate that 55% of the middle class in the ESA is in rural areas.

Second, rural purchases of food are now substantial. The traditional situation was one of farm households being either self-sufficient or buying a little of their food. While Mellor (1976) in India and Reardon et al. (1988) in Africa pointed out that many rural households, even farmers, were net buyers of grains, the share of total consumption from purchases was on average traditionally low. This of course differed by semi-arid versus more humid areas, such as in Senegal, where purchases of food were important for the drought prone areas and much less important in the relatively lush areas (Kelly et al., 1993).

But recent data show high shares of purchased food in rural diets in Africa and Asia. In ESA, Dolislager et al. (2015) show rural households bought 44% (in value terms) of food they consume; Liverpool-Tasie et al. (2016b) show 70% in Nigeria. Sibhatu and Qaim (2017) show that 42% of calories consumed of rural Ethiopian households are from purchased foods. In the Reardon et al. (2014b) Asian study, rural households purchase share averaged 73%. Third, recent evidence shows these purchases are mainly financed by rural nonfarm employment (RNFE) as well as by agricultural product sales. Very little is purchased on credit, whether from informal or formal sources (Adjognon et al., 2017, for Africa). RNFE is roughly 40% of rural household incomes in Africa and Asia, and a much higher share of total cash available, and far higher than migration income or credit flows (Haggblade et al., 2007).

(c) Challenges to farmers from longer supply chains

There are challenges for farmers of longer supply chains, with urban markets becoming the main markets faced by farmers.

First, in longer supply chains, small farmers face more competition. Urban traders seek a diverse set of zones to reduce seasonality and supply risk. They have the logistics and purchasing power to require that different regions compete for their procurement. This means that farmers from a given zone no longer have a "protected" (by transaction cost barriers) local market but are competing with farmers large and small from other zones for the urban market.

Local farmers also vie with imports for city markets. But local farmers and rural processing enterprises have even to vie with cheap packaged processed foods from urban areas coming into rural areas, often via the conduit of secondary city/rural town markets (Reardon et al., 2007b). An example is Indofoods' packaged noodles and drinks into rural towns in Indonesia and Nigeria (Liverpool-Tasie et al., 2017), or Maseca's ready-made tortillas or mix coming into rural towns in Mexico (Rello, 1996).

Second, as urban markets modernize with the rise of supermarkets (discussed below), the competition by a region for supplying to urban supermarket procurement centers heightens, and becomes more challenging yet with the imposition of private grades and standards. Reardon et al. (2007) and Berdegue et al. (2005) illustrate this for the cases of Mexico and Central America. Large processing firms and supermarkets based in towns also tend to prefer supply regions with low transaction costs, and eschew contracting with farmers in hinterland zones (Barrett et al., 2012).

Third, longer supply chains mean heightened vulnerability to shocks that beset long exposed chains – shocks of climate change (Reardon and Zilberman, 2017), energy cost spikes, disease outbreaks, food safety crises, and sociopolitical strife. A case in point is the vulnerability to all these represented by the south-north and north-south maize and egg supply chains in Nigeria (Liverpool-Tasie et al., 2016).

4.2.3. Change in "industrial organization" structure of the system

a) Increase in the "post-farmgate" segments

In a local traditional short supply chain, very little of the value added of the chain is due to off-farm components of the supply chain – the midstream (wholesalers, logistics agents, processors) and downstream (retailers). The farmer sells the grain or milk to neighbors and transports it herself. The consumer buys the raw product and processes it herself.

As the chain grows longer, the market volume grows large enough, and economies of specialization emerge in the midstream and downstream segments, the off-farm components' shares rise compared with traditional chains. Typically the farmer's share in the total value added of the supply chain drops as the counterpart to post-farmgate segments' development. Reardon (2015) reviewed evidence and produced a rough estimate for Asia and Africa food supply chains of about 40% of value added from farms, 40% from midstream (what he calls the "hidden middle" as this segment is usually ignored in both policy debates and research) and 20% from the downstream. This share varies over products and regions.

b) Emergence of a "Quiet Revolution" of small off-farm food system enterprises

As supply chains develop to cities, and gradually consumers purchase processed products, there is a proliferation of midstream MSMEs in wholesale and processing, as well as upstream in input supply. This is part of the "transitional stage" and is the dominant situation now in Africa and South Asia. Recent studies in South Asia, China, Vietnam, and Africa have termed this a "Quiet Revolution" wherein tens of thousands of MSMEs emerge (Minten et al., 2010; Reardon et al., 2012b, 2014c). Four examples intrigue.

First, there has been a rapid emergence of MSME potato cold storages in Bihar (Minten et al., 2014) and Western Uttar Pradesh near Delhi (Das Gupta et al., 2010). The storages diffused due to a confluence of trends – the rise of nearby cities, the improvement of road links and electricity grids, the introduction of a disease-resistant and long-shelf-life potato varieties by the NARS, and a flood of private investments by local small/medium entrepreneurs.

Second, there has been a proliferation of SME "outsourced agricultural services". Examples include SME providing mobile combine services for small rice farmers in China (Zhang et al., 2017) and Myanmar (Belton 2017). There has also been a diffusion of "sprayer trader" services in mango areas of Indonesia and the Philippines: teams of skilled laborers equipped with sprayers and vehicles and ladders go from farm to farm and prune, spray, harvest, sort, and market mangoes for small and medium farmers targeting demanding urban and export markets (dela Cruz et al., 2010; Qanti et al., 2017).

Third, Minten et al. (2016) show that the value chain of teff (the leading cereal in Ethiopia) has developed rapidly over the past decade. There has been a proliferation of MSME mills-cum-retailers, wholesale, and logistics firms spurred by Addis's development and road improvements. The development of the teff value chain is in turn correlated with increasing adoption of modern inputs by farmers, and shift from cheap red varieties to the more expensive, higher quality white teff varieties and uptake of improved varieties of the latter.

Fourth, in Senegal in the past decade, the millet supply chain has rapidly transformed with the emergence of processed and prepared millet products. Badiane (2016) shows that this transformation has featured the development by small female-headed enterprises of branded packaged millet and millet-cum-dairy products for the Dakar market.

c) Concentration and dis-intermediation

As markets expand with longer supply chains, and especially where there are economies of scale or economies of scope, such as in processing or retail procurement and storage, and large-scale firms are more efficient than small firms, segment concentration tends to occur. Some segments of a chain may concentrate while others stay fragmented for some time. For example, in the dairy sector in Zambia, some small farms sell to large processors who sell some of their output to supermarkets (Neven et al., 2016). In the Bangladesh rice sector, town-based larger wholesalers have competed out of the market many small rural brokers, but the wholesalers sell on to many small urban millers and small retailers (Minten et al., 2013).

Reardon (2015) conceives of the evolution of concentration as a "J curve" with three stages. The first stage in many developing countries has been the establishment of government grain retail and wholesale parastatals to serve emerging urban markets, building economies of scale as a counter to the traditional fragmented supply chain, and to obviate what governments perceived as "exploitative traders." This is the leftmost part of the J of concentration over time.

The second stage occurs after market liberalization and the privatization of the parastatals. The vacuum thus left attracts investments at least initially by many MSMEs. This is the bottom of the J curve; it can be broad or narrow depending on how long the MSMEs can hold out against competition or acquisition by large private firms.

The third stage is the steep rightmost part of the J, and is the re-concentration that occurs after competition thins the ranks of MSMEs and large firms emerge to outcompete or buy the small firms. The emergence is usually spurred by FDI liberalization as seen in Latin America in the 1980s/1990s and domestic investment regulation relaxation (such as "de-reservation" in India in the late 1990s. The large firms arise at first in the midstream and downstream (processing, wholesale/logistics, retail, and fast-food) and later in upstream (seed, chemical, and machine agribusiness firms) (Reardon et al. 2003 for supermarkets; Reardon and Timmer, 2012 for processing and wholesale; Popkin and Reardon, 2017 for fast food). Supermarkets in Central America have shifted to buying directly from agribusiness firms for crops in which the latter are engaged (e.g., pineapples, bananas) (Berdegué et al., 2005).

Also, large scale firms in different segments facilitate each other's growth through "coevolution." To reduce transaction costs and make sure private standards are met, supermarket chains tend to source from large processors. An example of this is supermarket chains in China sourcing mainly from large rice mills (Reardon et al., 2014c). Large processors target product differentiation to the requests of supermarkets, such as for milk and juice products by Nestle in Brazil (Farina et al., 2005). Large logistic and wholesale multinationals as well as processors "follow" supermarket chains into new countries, in "follow sourcing", as with Baakavor following Tesco into China (Reardon et al., 2007b).

Furthermore, large firms have a tendency to try to "cut out the intermediaries" and sell or buy directly – "disintermediation." This is done mainly to cut costs, as well as control quality or assure traceability. For example, larger wholesalers based in towns and cities have in India gone well along the path of eliminating use of traditional village brokers in order to buy directly from rice and potato farmers (Reardon et al., 2012b).

Finally, supermarkets and processing companies also have a tendency for "re-intermediation" - to shift from procurement on the traditional fragmented spot market to use, as much as possible, specialized, dedicated wholesalers to procure and market (Reardon and Berdegué, 2002). They are charged with applying quality and safety standards of the chains or processor, selecting regular suppliers such as farmers or supplier villages or coops who can meet the standards, and collecting or marketing exclusively for the chain or processor. An example is large rice millers in China relying on specialized agents to wholesale their branded packaged rice (Reardon et al., 2012b), and supermarkets in Latin America and Africa and China using dedicated wholesalers to source produce according to the private quality standards of the chains (Reardon and Berdegué, 2002 for Latin America, Weatherspoon and Reardon, 2003 for Africa, and Hu et al., 2004 and Michelson et al., 2017 for China).

5. Transformation of Food systems: focus on conduct

5.1. Endogenous transfer, co-evolution, and innovators' strategic system design

Many basic industrial and agricultural innovations were generated in the past 200 years since the British industrial revolution (itself partly based on the earlier Chinese innovation of horizontal loom, Braudel, 1979), and the subsequent agriculture technology and food system revolutions in the US and Western Europe. In particular in the past 100 years food system technology innovations emerged (often the fruit of machine engineering and chemistry linked to the industrial revolution) in the US and Western Europe. These were two way drivers in the food system transformation in these two regions. These technology innovations were in agriculture (such as chemical fertilizer, hybrid maize, tractors, pesticides, genetic modification, and so on), in processing and wholesale and transport (motorized mills, trucks, refrigeration, freeze drying, and so on), and in market organization and communication (chain stores, self-service retail, supermarkets, private standards, ICT).

Many of the food system innovations from the US and Western Europe were then transferred and adapted in developing Asia, Africa, and Latin America in the past 50 years in the system transformation waves as demand side and policy conditions grew receptive and propitious for their transfer. The channels of transfer included: (1) massive waves of foreign direct investment (FDI) by agribusiness, processors, logistics and wholesale, and retailers; (2) investments by local entrepreneurs and public sector in innovations from the US or Western Europe they observed in FDI activities or on a business trip or university education, or read about on the internet.

The local private entrepreneurs and public sector in developing countries as well as innovating "Western" companies diffused those initial innovations, adapting and modifying them to local conditions. Just as in the "West" the initial innovations had developed as packages of inter-dependent innovations (such as the example of Tyson with genetic variation, contracting, private standards, piecing and cooling or freezing, long distance transport, and marketing in supermarkets), the transfer of one or more innovations, in technology or organization, brought with it the cluster of other related innovations both in technology and products, and in market organization.

Of course, not all of the basic innovations during the past 50 years were transferred initially from the "West." There was a wave of technology innovations, some basic and new and others applications and adaptations of prior innovations generated in international research institutes based in developing countries (such as IRRI's developed of modern varieties of rice in the 1960s in the Philippines, David and Otsuka, 1994) and in the large NARS in the developing regions. Examples include the foundational work in rice varieties in Taiwan and Japan in the 1920s-1930s and China and India in the 1950s-1970s (Barker and Herdt with Rose, 1985) and Argentina and Brazil (for no-till cropping technology innovation in the 1960s-1970s, see Trigo et al., 2009). In other NARS, there was significant adaptation work done that amounted to innovation in application, such as the Zaria maize work cited below.

Technology and product innovations are not "neutral" in their impact on the structure and conduct of food systems. The impact itself is often endogenous to the deliberate system designs of the innovator, as argued by Zilberman et al. (2017). They examine the proactive links between innovators' innovations and their "implementation," to generate and protect an initial advantage and profit arising from the innovation's superiority (in cost or quality or safety) to the technology or product it supplants. They depict as endogenous the structure and the conduct of the supply chain based on that innovation.

In that sense then, the food system changes we observe, especially in the modern phase, are emanations of the strategies of innovating companies. These strategies are sets of technologies and institutions and organizations chosen to implement the innovations. But they also "induce" innovation in other companies to "co-evolve" and help (symbiotically) the initial innovators implement the innovation. An example of this is given below of co-evolution of Nestle and Tetrapak investments in the Brazilian dairy industry.

Understanding both the role of public research and private innovators, and the linkages between technological, organizational, and institutional innovations in developing food systems, is central to our analysis. Below we explore in more detail these innovations.

5.2. Organizational and institutional change

First, organizational and institutional change occurs at different rates over products. Thus, in Mexico, for grains and meat one can find fully coordinated supply chains from farmers to supermarkets, with (1) branding and packaging; (2) direct purchase from suppliers or special agents, (3) distribution centers, (4) public and private standards, and (5) some contracts. But for fresh produce, one finds supermarkets relying on a mix of: (1) spot market relations in wholesale markets, (2) off-market specialized wholesalers such as Pedraza, and (3) direct contracts with large agribusinesses (Reardon et al., 2007).

Second, product quality and safety standards are an important coordinating "institution" in transforming food systems, emerging in three stages.

(a) In the 1970s/1980s in developing countries there was a gradual emergence of public standards of quality to allow for long-distance grain trade with low transaction costs and risk, and phytosanitary public standards to allow for animal and horticulture product trade.

(b) With product differentiation and the rise of trade in perishables, private standards for quality and safety began to emerge in the 1990s and 2000s especially manifest in export and processing. These were formulated by supermarket chains, large processors, and fast food chains to reduce losses in processing, increase shelf life, control quality and consistency, and assure safety (Reardon et al., 2001; Henson and Reardon, 2005; Swinnen, 2007). Examples include Nestle's quality certification for grated coconut in Brazil (Farina et al., 2000) and potato variety specification for French fry production by McCain's for McDonald's in Argentina (Ghezan et al., 2002).

(c) Gradually governments have instituted public food safety regulations for retail and food service (for example, in China, Jia and Jukes, 2013).

Third, finance arrangements evolved as coordination mechanisms, in three stages.

(a) In traditional systems, traders "tie credit," advancing money or inputs to the farmer at the start of the season and expecting the harvest from that farmer at a prearranged price and with an implicit interest rate (Bardhan, 1980).

(b) In transitional systems, there is competition among traders and risks of side selling, and farm households have off-farm cash sources. Tied credit disappears or is rare (e.g., Adjognon et al. 2017 for Africa). These show that formal and even informal finance are rare for farmers for agricultural investments; most cash is supplied from retained earnings form off farm jobs and farm product sales.

(c) In modern supply chains, in the cases where food industry firms must rely on small farmers to complete their supply, and small farmers face “idiosyncratic market failures” for credit and inputs, food industry sometimes use “resource provision contracts” (Austin, 1981) (for Latin America, Key and Runsten, 1999, for Madagascar, Minten et al., 2009).

5.3. Technological change along the chain

5.3.1. Farm technologies

Breeding research and variety change have been fundamental forces in fueling the “throughput” of feedstock in the transforming food system. R&D supply chains for new seeds and other inputs depend critically on a combination of the development of private seed markets as well as private and public sector breeding of improved seeds.

There are two ways we can link product demand change (diet change) over a product cycle (niche to commodity to differentiated products) and food system transformation, to breeding research.

The first path has received the most attention: grain breeding for drought or flooding and disease resistance and adaptation to small farmer conditions. The best known example is the Green Revolution and the system of NARS and IARCs that emerged to form R&D supply chains of new seeds (Lipton with Longhurst, 1989; Hayami and Ruttan, 1971, Binswanger, 1978). Another example is the shift from local varieties to breed for broad agroecological adaptation, such as the breeding of maize to fit drier areas an institute in Zaria in Northern Nigeria in the 1980s (Byerlee and Eicher, 1997).

The second path links product cycle, breeding, and "commoditization." This path has received little attention in the literature. One variant has been a focus on breeding for traits of quality and ability to store and process. A good example is the shift from traditional flint to innovated/bred dent maize in output composition induced by the take-off of industrial maize milling in the mid-1800s in the US. Research to breed for quality and processing has recently emerged in developing countries as urban demand rose. An example is teff variety breeding for quality for the urban Ethiopian market (Minten et al., 2016) and rice quality in Bangladesh (Minten et al., 2013).

5.3.2. Non-seed inputs to support farming intensification

Supply chain development, urbanization, and industrialization of external input supply tend to be correlated. This drives down the cost of capital inputs (irrigation equipment, seeds, fertilizer, insecticides, herbicides, tractors and combines and sprayers), inducing their diffusion. Both the private sector, IARCs, and NARS have been engaged in R&D over the past century that have influenced the quality and cost (and existence) of these inputs. Four examples of private sector R&D cum extension supply chains of these innovations are of interest.

First, as labor costs rose in the US and the UK in the 1940s, herbicides were created by private companies and government and were used to substitute for hand weeding. This innovation diffused in the US over the 1940s to the 1990s (Swinton and van Deynze, 2017). Due to increases of labor costs in developing regions, a parallel adoption of herbicides has occurred in waves similar to the system transformation waves from the 1970s to the 2010s (Haggblade et al., 2017).

Second, as demand for machine use rose in the US in the 1800s as farms extensified and labor constraints appeared, the combine was invented by private persons in the US and Scotland. It diffused over the century, shifting from horse to steam to gas engine powered, with a string of innovations by companies such as John Deere. It was then adapted for small farms in the 1970s in Japan by Kubota, and from there diffused widely over developing Asia and into Africa in the subsequent decades.

Third, as demand for water in horticulture rose in Germany, Australia, Israel, and California from the 1860s to the 1960s, there were a series of innovations from clay to plastic tubing that came to be termed drip irrigation. Again, as with the innovations above, starting in the 1970s it was adapted and diffused to developing countries, with innovations by companies like Netafim of Israel and then Jain Irrigation of India.

Fourth, Notore Chemicals in Nigeria are a major supplier of agro inputs. They have developed a system for training and input distribution which uses local rural people to be their sales agents and credit and extension officers (Liverpool-Tasie et al., 2015).

5.3.3. Post-farmgate technology change

As with farm technologies, a gradual increase in wage rates combined with a decrease in physical capital prices (from local industrialization and imports) induced midstream and downstream capital intensification and productive capital upgrading. Demand side factors such as demand for new products, new quality and safety attributes, and greater and more storable volumes also induced technology change.

R&D supply chains to create and deliver new off-farm technologies noted below developed along with investments in the off-farm segments as “induced technological innovation.” These sometimes started as basic science innovations in public research institutions with subsequent adaptation and further innovation by private companies. Many were the inventions of individual inventors, or of R&D units of companies. Some were all three of these, such as the cluster of inventions and improvements around freezers or tractors. As in farm technologies, much of the initial innovation occurred earlier, in currently developed countries historically, and then was transferred and adapted to developing countries. We provide several prominent illustrations.

(a) Logistics innovations

These have been fundamental to the elongation and de-seasonalization of the food system. Minten et al. (2016), for Ethiopia, show a rapid shift from transport of teff by foot (head loads) to animal transport (donkey/horses, carts), to motorized transport, and then from small trucks of 4-5 tons to truck-trailers of 20 tons – a thousand years of transport change in a decade. Systems that had been relatively local switched to long distance commerce as large trucks and train lines combined to move potatoes from Northern to Southern India, abetted by potato varieties with tougher skins to transport further and store longer (das Gupta et al., 2010). A surprising case occurred in Myanmar: in 2011, bus transport was privatized and liberalized; bus lines proliferated and competed. One way they competed was by adding an iced cold shelf in the buses for fish to be transported from aquaculture areas in the south to Mandalay in the north. This gave rise to nearly 200,000 tons of fish moved by small merchants via many buses (Belton et al., 2017). Zhang and Hu (2014) note the large role of infrastructure investments in improving logistics in the potato value chain from hinterland Gansu to the coastal cities.

(b) Processing scale and clustering innovation

For example, as animal product value chains have transformed, poultry, fish, milk cow, and hog rearing has shifted its center of gravity from scattered small farms to peri-urban agglomeration to clustered sites with small and medium commercial farms further from cities near cheap input bases (for aquaculture in Bangladesh, see Hernandez et al., 2017; dairy in Brazil, Farina et al. (2005); hogs and chickens in Thailand, see Poapongsakorn, 2012; for hogs in China, see Schneider (2011). There has been a concomitant rise of large processing firms for pigs and chickens, with location of large farms and large processing firms near the cities of China and Thailand, in a major shift away from scattered countryside processing operations in the 1990s and before.

(c) Freezing and Packaging innovations

These are important to elongation of supply chains from near cities to near areas with low cost natural resources. For example, with rapid development of the frozen fish industry, fish is increasingly shipped longer distances within countries. An example is frozen fish from aquaculture areas in the South of China to Beijing, mainly developed in the 2010s as an outgrowth of an initial export operation base (Bai et al., 2017). Another case is the rise of frozen potatoes shipped long distance in Argentina to the burgeoning fast food chains (Ghezan et al., 2002), and frozen green vegetables and sweet corn in Chile (Milicivec et al., 1998).

A similar change took place in dairy in Brazil (Farina et al., 2005). There was a combination of four internationally-transferred technology and organizational innovations that led to a massive increase in milk consumption, a rise in average dairy farm size and the exit of many small farms, and a spatial shift from peri-urban production to dairy production in cheap grain areas. The innovations include: (1) large scale dairy processing, brought by Nestlé and Parmalat who intensively invested in Brazil in the late 1980s after liberalization of FDI; (2) supermarket chains spread in the late 1980s and early 1990s with liberalization of retail FDI; the chains sought to source from large dairy companies to cut transaction costs; (3) the introduction by the large companies of UHT (ultra-high temperature) treatment of milk (invented in Denmark in 1910) which allowed milk to be stored at ambient temperatures if in vacuum packed containers, and thus the spread of milk retail even to areas yet without home refrigerators; (4) the layered vacuum-packed container technology invented in 1952 by Tetra Pak of Sweden, and brought to Brazil in the 1980s to facilitate mass processing of UHT milk. Farina et al. (2005) show that UHT milk went from 10% to 90% of milk consumed in Brazil just in the decade of the 1990s.

(d) Extrusion for feed and noodles

Food technology breakthroughs have been part of revolutions in food systems for a long time, from the invention of beer brewing in China and Egypt six millennia ago, and tofu and miso processing two millennia ago in China. With the recent rapid transformation of the food system, a dense cascade of such innovations has occurred this time packed in short time. These innovations reduced the cost, increased the shelf life, and vastly increased the hedonic attributes range, of processed products. For example, in baking there were a series of advances in extrusion, frozen dough production, emulsifiers and enzymes, microwaves, ovens, and automation over the 20th century (Kamel and Stauffer, 1993). These innovations mainly started in Europe and the US, and then were transferred to developing regions. The same occurred with extrusion used for pelleted feeds and noodles. This led to rapid diffusion of pelleted, floating feed for example in Bangladesh aquaculture (Hernandez et al., 2017), and diffusion of Japanese ramen noodles manufactured by Indofoods in Nigeria (Liverpool-Tasie et al., 2017).

(e) Traceability, inventory, and safety monitoring technologies

Demand for time saving in shopping induced transfer of retail "technologies" and organization, like supermarkets and chain stores. An example is the adoption of bar codes and electric scanners for inventory control. Food safety concerns among urban consumers of perishables and rural and urban consumers of maize and peanut products induced food safety cum waste control measures like pasteurization of milk, addition of aflatoxin binders in stored maize by traders and millers, and humidity measuring devices and grain driers by traders and warehouse owners.

5.3.4. Emerging "Disruptive Technologies" in the Food System

In the past century there has been an intense stream of major technological innovations in agriculture and rest of the food system. At the time of their emergence, many of the technologies we discussed above were "disruptive" in the sense that they quickly and fundamentally changed the spatial or industrial organization structure of the system, its overall volume, its seasonality, and so on. Recent times have also brought a new generation of technologies that promise to, and have started to create sweeping changes in the overall global economy as well as food systems. We note three examples.

The first is the emergence of gene-editing, CRISPR (Ledford, 2015). This promises to reduce the cost and time and increase the breadth of applications of genetic modification. That may change the amplitude and frequency of changes in the system, such as rapid iteration of changes in disease and drought resistance, improving quality, and increasing shelf life of products.

The second is the rapid development of robots in the food system (Reardon et al., 2017). The general path of diffusion has been from upstream to downstream, and from developed to developing countries. The innovation has moved from incorporation of computer elements into existing machines (such as precision farming tractors and electric-eye conveyor belts for sorting fruit) to stand-alone non-autonomous machines (such as directed farm surveillance drones, restaurant food preparation robots such as at Zume Pizza in San Francisco) to stand-alone autonomous machines emerging (pre-programmed or real time self-directing such as Bayer's pilot "spider robots" that walk fields and monitor and perform activities such as spot application of herbicides, or warehouse box packers and stackers). These technologies are being applied both where labor is becoming more expensive but also in situations of cheap labor but other factors determining their use (such as the recent emergence of cashier-less supermarkets in India; Indiaretailing Bureau, 2017). The rapid rise of robots will have a series of easily foreseen consequences for the food system (such as a reduction in unskilled labor in all segments) and unforeseen and complex changes wrought on the structure and conduct.

Third, the application of emerging big data tools for food systems research may also speed up the way we organize, convene, and inspire new agricultural research opportunities in the future (http://bigdata.cgiar.org)

6. Food system transformation's impacts

The immense changes wrought by the rapid and recent food system transformation have had a series of impacts. Here we indicate emerging evidence and points of debate on these impacts. However, a thread that runs through all the impacts is that the results have been mixed, with transformation being a two edged sword bringing benefits and challenges.

6.1. Impacts on the entire food supply chain: debunking the "waste myth"

System transformation has increased the volumes and length of supply chains, and de-seasonalized supply. One thus moves away from "niche" local markets to nationally integrated and often more efficient markets. This leads to better price integration and smaller marketing costs (as shown in cereal market analysis in Ethiopia; Minten et al., 2014b).

But the elongation of supply chains as well as the increase of perishables has raised concerns internationally, since the 1970s, that waste and loss in developing country food supply chains are substantial; for example, FAO (2011) hypothesizes, repeating a position taken for decades, that there is as much as 20%-30% waste and losses for cereals and pulses and meat and milk and fish, 40% for roots and tubers, and 50% for fruits and vegetables.

However, the hypothesis of high shares of waste is quite doubtful as revealed by empirical field studies. Bellemare et al. (2017), Affognon et al. (2015), and Sheahan and Barrett (2017) argue that measures of food waste are conceptually flawed and have led to an over-estimate of waste in food systems. Most systematic survey-based studies of actual actors in the supply chains tend to have much lower figures than the FAO hypotheses. Several of many possible examples follow:

a) Lipton (1982) in India had direct measurement-based findings of low loss rates, and at that time questioned the then extant FAO estimates of 30-50% loss in grains.
b) Greeley (1986, 1987) had similar findings of low waste/loss in rice in Bangladesh and shows that high waste/loss assertions/estimates from the 1970s that had become common wisdom were actually based on flawed data or no data.
c) A unique “stacked survey” based loss/waste measurement approach (Minten et al. 2016b and Reardon et al., 2012) that included details on waste in each segment of the value chains of potatoes and rice in China, India, and Bangladesh. They found only about 5% loss/waste over the whole supply chain for potato (excluding consumer level waste) and about 1% for rice.

d) A similar stacked survey estimate for post-harvest losses in the teff value chain in Ethiopia were found to be 2.2-3.3% of the teff harvest (Minten et al., 2016c).

e) Kaminski and Christaensen (2014) used national level representative surveys of farm households for post-harvest losses in Malawi, Uganda, and Tanzania, and found a range of 1.4% to 5.9%, much lower than the post-harvest loss estimate of 8% for grains by FAO (2011). They found that loss was concentrated among 20% of farms in hotter and humid areas, with less market access.

f) Reyes et al. (2016), in a survey of 575 wholesalers and retailers in Nicaragua and Honduras, found post-harvest losses among them to total 8% for beans and 21% for tomatoes.

6.2. Impacts on nutrition

There is mounting evidence that transformation of food systems has lowered the cost of food and reduced sharp seasonality in its supply. Some of the evidence is from the "quiet revolution" where the diffusion of SMEs in supply chains accomplished this; we return here to the example of potato cold storage proliferation in India (das Gupta et al., 2010; Minten et al., 2014), and processed teff for poor consumers in urban Ethiopia (Minten et al., 2016). Other evidence shows this for the "modern revolution" such as in dairy in Brazil and Argentina (Farina et al., 2005), grains and vegetables in Delhi supermarkets versus traditional markets (Minten et al., 2010, and for an overall review, Minten and Reardon, 2008.).

Moreover, processed foods and other time saving devices have positive consequences of liberation of women's time for education, labor market participation, and child care (for Nigeria, see Liverpool-Tasie et al., 2016b).

Yet there are a series of well-documented concerns of the rise of fast food and ultra-processed foods leading to obesity and health problems such as diabetes (Popkin, 2014, for Asia and Popkin and Reardon, 2017, for Latin America).

6.3. Impacts on inclusion or exclusion of small farmers

There are several recent reviews of the impacts of food system transformation on small farmers and the evidence tends to be mixed (Reardon et al., 2009).

On the one hand, longer supply chains link rural areas to growing urban markets; diversifying food systems open opportunities to farmers to grow high value crops, meat, fish, and dairy. Some farmers enter resource provision contracts as discussed in Gow and Swinnen (1998); and others enter contracts offering price stabilization compared with traditional spot markets (Michelson et al., 2015).

On the other hand, the available evidence shows that it tends to be the upper tier or half of small farmers who can access the modern channels, the urban markets, and the non-grain markets, as they require placement near enough to roads, water access, and specialized skills and equipment. Eventually as the chains modernize and increasingly demand quality and safety, those farmers reached must make basic investments in those attributes and that narrows the winners. The evidence shows that small farmers can still be included, but tend to not be the hinterland or asset-poor farmers (Reardon et al., 2009).

6.4. Impacts on off-farm employment in rural areas

Both from the high-value diversification products being produced, and the large amount of activity post-farm gate occasioned by longer and more developed supply chains, there is a great deal of rural nonfarm employment linked to food supply chains generated by the transformation. There is growing evidence that women and youth are especially benefitted as these are low entry barrier jobs in transport, commerce, food preparation, and small scale processing (for Africa, see Tschirley et al., 2016).

As the food system modernizes there is, however, a challenge presented by cheaper urban processed foods penetrating rural areas and displacing traditional small enterprises (Reardon et al., 2007b), as well as dis-intermediation and large scale distribution firms displacing petty traders.

6.5. Vulnerability of longer food supply chains

Developing countries face the trade-off between efficiency and reduction of supply risk to cities via diversification of supply sources as food systems develop, and increasing risks that can accost long exposed supply chains such as from shocks from climate, environmental degradation, food safety, disease, sociopolitical unrest, and energy costs. Reardon and Zilberman (2017) argue that the strategies and investments that supply chain actors are and will take to mitigate or cope with those shocks will probably hasten the transformation, and in particular the concentration of the system. This is a particular challenge to governments to help the hinterlands and asset-poor.

7. Implications for the agricultural research community

There are several key implications of our analysis of the pathways of transformation of food systems for agricultural research strategies of the IARCs and NARS.

First, IARCs and NARS have a strong vested interest in researching, understanding, and taking into account the whole food system and its transformation, adapting their strategies, plans, and choice and design of innovations in technologies and products. This also includes understanding the changing government policies, as well as private sector institutions (such as private standards) and procurement system and marketing organization. This is important for several reasons. Opportunities and bottlenecks along all three sets of supply chains determine the potential success of IARC/NARS innovations in the farming segment. Emerging requirements of the changing food system – in terms of product types, quality and safety attributes, shelf life, cost, consistency, seasonality, volumes, and so on - should influence priorities for IARC/NARS innovations. This will help to determine whether innovations in farm technology and products lead to profitable marketed output by farmers, and thus ultimately, whether farmers will have the incentive to adopt new technologies. It is important for the research community to take into account that farmers themselves have deeply changed from just a few decades ago, far more involved in markets, commercialization, having intensified and diversified farming, and IARC/NARS strategies need to keep up with that change.

Second, IARCs and NARS innovations need a supply chain to implement the innovations they generate. The upstream innovation is the beginning, not the end, of the process. The private sector in the food system is the centerpiece of the supply chain that delivers that upstream innovation. It is essential that IARCs/NARS understand the strategies, behavior, and needs of these two powerful sets of private sector actors, as the latter are essentially and in practical terms in charge of the direction of the entire food system. 25 years ago the private sector in the food system could be just a sidelight and "specialized" issue at the margin of food system thinking and agricultural research strategies: by becoming the dominant, central player in the food system, the private sector cannot be relegated to just a potentially interesting group to consult and observe at the edges. It is now at the center. It is now the group that decides what systems and structures will market and implement the innovations of technologies and products generated by the IARC/NARS. The ability of the latter to understand, adapt to, and selectively partner with the private sector will in the next decades be an important part of determining the performance of IARC/NARS innovations. In addition, important innovations are needed in transforming research institutions, investing in institutional change that would then be a key driver for technical change. There is a risk that rapidly transforming food systems would leave behind international and/or national public research organizations that are not transforming themselves to the new realities.

Third, the public research community needs to understand the importance of research on the off-farm components of the food system. Research on and productivity of processing, packaging, logistics, and commerce technologies have equal weight in the performance of the food system relative to the farm sector, and investment in research and development (R&D) value chains for these technologies and value chains for the inputs to these segments need a much higher profile in the context of the transformed food system where post farm segments occupy 40-70% of value added. An argument for post-farm-gate research (so that it allows reduction of marketing margins in value chains to improve efficiency in the value chain) is usually a win-win for consumers as well as for producers. Moreover, returns on research (RoR) at the farm level clearly depend on concomitant innovations in the supply chain to supply inputs for or market the output of the innovation.

Finally, we have signaled the importance of universities and CGIAR and NARS and companies forming public-private partnerships to generate and embody an "educational-industrial complex" (Zilberman et al. 2012) where innovation starts at university research centers and ideas are then further developed either by applied research centers (like the CGIAR and NARS) or by private sector entities (startups, small companies, and major corporations). The involvement of university researchers in further development of the innovations has been identified as the contributor to success as well as effective marketing extension and outreach that is an important component of the overall supply chain that renders innovation into marketable products that generate income and employment for actors all along the food system.

References

Adjognon, S.G., Liverpool-Tasie, LSO, Reardon, T., 2017. Agricultural input credit in Sub-Saharan Africa: Telling myth from facts. Food Policy 67, 93–105.

Affognon, H., Mutungi, C., Sanginga, P., Borgemeister, C., 2015. Unpacking postharvest losses in Sub-Saharan Africa: a meta-analysis. World Development, 66, 49-68.

African Development Bank, 2016. Feed Africa: Strategy for Agricultural Transformation in Africa 2016-2025. May. Abidjan: African Development Bank.

Amat y Leon, C., Curonisy, D., 1981. Nutrition in Peru. Lima: Universidad del Pacifico.

Austin JE, 1981. Agroindustrial Project Analysis. Baltimore, MD: Johns Hopkins Univ. Press

Badiane, O. 2016. Agro-Allied Industrialization and Regional Value Chains. Keynote Address. African Development Bank's African Economic Conference, Abuja, Nigeria, December 7.

Bai, N., Zhang, J., Reardon, T., 2017. Transformation of the Aquaculture Feed Market and Determinants of Farmers' Feed Purchasing Channels: Evidence from South China. East Lansing: Michigan State University working paper, Department of Agricultural, Food, and Resource Economics.

Bardhan, P.K., 1980. Interlocking factor markets and agrarian development: a review of issues. Oxf. Econ. Pap. 32(1), 79–98.

Barker, R., Herdt, R.W., with Rose, B., 1985. The rice economy of Asia. Washington, D.C.: Resources for the Future and Los Baños: The International Rice Research Institute.

Barrett, C.B., Bachke, M.E., Bellemare, M.F., Michelson, H., Narayan, S. Walker, T.F., 2012. Smallholder Participation in Contract Farming: Comparative Evidence from Five Countries. World Development, 40(4), 715-30.

Bellemare, M., Çakir, M., Hanawa Peterson, H., Novak, L., Rudi, J., 2017. On the measurement of food waste. American Journal of Agricultural Economics, 99(5), 1148-1158.

Belton, B., 2017. The rapid rise of mechanization services (and outsourcing?) in Myanmar Powerpoint presented at the workshop on Outsourced Agricultural Services at the Institut National de Recherche Agronomique, Toulouse, April 26.

Belton, B., Hein, A., Htoo, K., Seng Kham, L., Sandar Phyoe, A., Reardon, T., 2017. The emerging quiet revolution in Myanmar's aquaculture value chain. Aquaculture, http://dx.doi.org/10.1016/j.aquaculture.2017.06.028

Bennett, MK. 1954. The World's Food. New York: Harper.

Berdegué, J.A., Balsevich, F., Flores, L., Reardon, T., 2005. Central American supermarkets' private standards of quality and safety in procurement of fresh fruits and vegetables. Food Policy, 30(3), June, 254-269.

Binswanger, H.P. 1978. Induced Technical Change: Evolution of Thought. in H.P. Binswanger and V.W. Ruttan, Induced Innovation: Technology, Institutions, and Development. Baltimore: Johns Hopkins University Press.

Bloch, R., Fox, S., Monroy, J., Ojo, A., 2015. Urbanisation and Urban Expansion in Nigeria. Urbanisation Research Nigeria (URN) Research Report. London: ICF International.

Braudel, F., 1979. Civilisation matérielle, économie et capitalisme, XVe-XVIIIe siècle. Paris: Armand Colin.

Bricas, N., Muchnik, J., 1985. Technologies autochtones et artisanat alimentaire urbain. In Bricas N., Courade, G., Coussy, J., Hugon, P., Muchnik, J. (ed.) Nourrir les villes en Afrique sub-saharienne. Paris: L'Harmattan, 293-310.

Byerlee, D., Eicher, C. (ed.), 1997. Africa's Emerging Maize Revolution. Boulder: Lynne Rienner Publishers.

Das Gupta, S., Reardon, T., Minten,, B., Singh, S.,. 2010. The Transforming Potato Value Chain in India: From a Commercialized-Agriculture Zone (Agra) to Delhi. Report of the Value Chains Component of Asian Development Bank RETA (13th) IFPRI Project on Policies For Ensuring Food Security In South And Southeast Asia. October.

David, C.C., Otsuka, K. (ed.), 1994. Modern rice technology and income distribution in Asia. Boulder: Lynne Rienner Publishers; Manila: International Rice Research Institute.

Dela Cruz, A., Hernandez, R.A., Digal, L., Reardon, T., Qanti, S., Minten, B., 2010. Mango Farmers, Sprayer-Traders, and Modern Market Channel Participation in Pangasinan Province, Philippines: Survey-based Evidence and Implications. Report of MSU to Asian Development Bank under the project Strengthening Institutions for Investment Climate and Competitiveness. April.

Dolislager, M.D., Tschirley, D., Reardon, T., 2015. Consumption patterns in Eastern and Southern Africa. Report to USAID by Michigan State University, Innovation Lab for Food Security Policy, May.

FAO. 2011. Global Food Losses and Food Waste: Extent, causes and prevention. Rome: FAO.

Farina, EMMQ, Gutman, G.E., Lavarello, P.J, Nunes, R., Reardon, T., 2005. Private and public milk standards in Argentina and Brazil. Food Policy, 30(3), June, 302-315.

Farina, E.M.M.Q., Marino, M.K., Guedes, T.M., 2000. Nestlé-Socôco: Private Certification In Quality Management. Case study presented at the IAMA Maple Leaf Conference, Chicago.

Ghezán, G., Mateos, M., Viteri, L., 2002. Impact of supermarkets and fast-food chains on horticultural supply chains in Argentina. Development Policy Review 20 (4), 389-408.

Gow, H.R., Swinnen, JFM. 1998. Up- and downstream restructuring, foreign direct investment, and hold-up problems in agricultural transition. Eur. Rev. Agric. Econ. 25(3), 331–50.

Greeley, M., 1986. Food, technology and employment: The farm-level post-harvest system in developing countries. Journal of Agricultural Economics 37(3), 333-347.

Greeley, M., 1987. Postharvest Losses, Technology, and Employment: The Case of Rice in Bangladesh. Westview Special Studies in Social, Political, and Economic Development.

Haggblade, S., 2011. Modernizing African Agribusiness: Reflections for the Future. Journal of Agribusiness in Developing and Emerging Economies 1 (1), 10–30.

Haggblade, S., Hazell, P., Reardon, T. (ed.), 2007. Transforming the Rural Nonfarm Economy: Opportunities and Threats in the Developing World. Baltimore: Johns Hopkins University Press.

Haggblade, S., Minten, B., Pray, C., Reardon, T., Zilberman, D., 2017. The Herbicide Revolution in Developing Countries: Patterns, Causes and Implications. European Journal of Development Research. 29(3), June, 1-27.

Hayami, Y., Ruttan, V.W., 1971. Agricultural Development: An International Perspective. Baltimore: Johns Hopkins Univ. Press.

Henson, S., Reardon, T., 2005. Private agri-food standards: Implications for food policy and the agri-food system. Food Policy, 30(3), June, 241-253.

Hernandez, R.A., Belton, B., Reardon, T., Hu, C., Zhang, X., Ahmed, A., 2017. The 'quiet revolution' in the aquaculture value chain in Bangladesh. Aquaculture, http://dx.doi.org/10.1016/j.aquaculture.2017.06.006

Hirschman AO. 1958. The Strategy of Economic Development. New Haven: Yale University Press.

Hollinger, F., Staatz, J., 2015. Agricultural Growth in West Africa: Market and Policy Drivers. Rome: Food and Agricultural Organization of the United Nations.

Hu, D., Reardon, T., Rozelle, S., Timmer, P., Wang, H., 2004. The Emergence of Supermarkets with Chinese Characteristics: Challenges and Opportunities for China's Agricultural Development. Development Policy Review, 22(4), Sept., 557-86.

Indiaretailing Bureau. 2017. HyperCity goes cashier-less, opens two self check-out stores in Hyderabad, www.indiaretailing.com, November 3, accessed December 4.

Indiastat. 2010. Datanet India Pvt. Ltd, available from www.indiastat.com.

Jia, C., Jukes, D., 2013. The national food safety control system of China – A systematic review. Food Control, 32(1), 236-245.

Kamel, B., Stauffer C., 1993. Advances in Baking Technology. Amsterdam: Springer.

Kaminski, J., Christaensen, L., 2014. Post-harvest loss in Sub-Saharan Africa – what do farmers say? Global Food Security 3, 149-158.

Key, N., Runsten, R., 1999. Contract farming, smallholders, and rural development in Latin America: The organization of agroprocessing firms and the scale of outgrower product. World Development, 27(2), 381-401.

Kelly, V., Reardon, T., Fall, A.A., Diagana, B., McNeilly, L., 1993. Final Report of IFPRI/ISRA Project (1988-1992) on Consumption and Supply Impacts of Agricultural Price Policies in Senegal. Washington: IFPRI.

Kennedy, E., Reardon, T., 1994. Shift to Non-traditional Grains in the Diets of East and West Africa: Role of Women's Opportunity Cost of Time in Prepared-Food Consumption. Food Policy, 19 (1), February, 45-56.

Ledford, H., 2015. CRISPR, the Disruptor. Nature, 522, 4 June, 20-24.

Lipton, M. 1982. Post-harvest technology and the reduction of hunger. Institute of development studies Bulletin, 13(3), 4-11.

Lipton, M. with R. Longhurst. 1989. New Seeds for Poor People. Baltimore: Johns Hopkins University Press.

Liverpool-Tasie, LSO, Adjognon, S., Kuku-Shittu, O., 2015. Productivity effects of sustainable intensification: The case of Urea deep placement for rice production in Niger State, Nigeria. African Journal of Agricultural and Resource Economics. 10 (1), 51-63.

Liverpool-Tasie, LSO., Omonona, B., Sanou, A., Ogunleye, W., Padilla, S., Reardon, T., 2016. Growth and transformation of chicken and eggs value chains in Nigeria. Food Security Policy Research Paper No. 22. East Lansing, Michigan: Feed the Future Innovation Lab for Food Security Policy. http://fsg.afre.msu.edu/fsp/nigeria/FSP_Research_Paper_22_Finaldocx.pdf

Liverpool-Tasie, LSO, Reardon, T., Adjognon, S.G., Sanou, A., 2016b. The Economics of the Transformation of Household Food Consumption in West Africa, Contributed paper presented at AAEA annual meetings, Boston, August 1.

Liverpool-Tasie, LSO, Reardon, T., Abagyeh-Igbudu, I.J., 2017. Rapid agri-food system transformation in sub-Saharan Africa: Evidence from processed food inventories in Nigeria. Paper presented at the 2017 Annual Meeting, Agricultural and Applied Economics Association, Chicago.

Mellor, J.W. 1976. The New Economics of Growth: A Strategy for India and the Developing World, Ithaca: Cornell University Press.

Michelson, H., Boucher, S., Cheng, X., Huang, J., Jia, X., 2017. Connecting supermarkets and farms: the role of intermediaries in Walmart China's fresh produce supply chains. Renewable Agriculture and Food Systems. January. 10.1017/S174217051600051X : 1-13.

Michelson, H., Reardon, T., Perez, F., 2012. Small Farmers and Big Retail: Trade-Offs of Supplying Supermarkets in Nicaragua. World Development, 40(2), 342–354.

Milicevic, X., Berdegue, J.A., Reardon, T., 1998. Impacts on rural farm and nonfarm incomes of contractual links between agroindustrial firms and farms: The case of tomatoes in Chile. In Proceedings of the meetings of the Association of Farming Systems Research and Extension (AFSRE), November 30–4 December, Pretoria, South Africa.

Minten, B., Reardon, T., Chen, KZ. 2010. The Quiet Revolution of Traditional Agricultural Value Chains in Asia: Evidence from Staple Food Supply to Four Mega-Cities. Report of the Value Chains Component of Asian Development Bank RETA (13) IFPRI Project on Policies For Ensuring Food Security In South And Southeast Asia. December.

Minten, B., Engida, E., Tamru, S., 2016c. How big are post-harvest losses in Ethiopia? Evidence from Teff. ESSP Working Paper 93, Addis Ababa: IFPRI, July.

Minten B., Randrianarison L., Swinnen, JFM., 2009. Global retail chains and poor farmers: evidence from Madagascar. World Dev. 37(11), 1728–41.

Minten, B., Murshid, KAS., Reardon, T., 2013. Food quality changes and implications: Evidence from the rice value chain of Bangladesh. World Development, 42, February, 100-113.

Minten, B., Reardon, T., 2008. Food Prices, Quality, and Quality's Pricing in Supermarkets vs Traditional Markets in Developing Countries. Review of Agricultural Economics, 30(3), Fall, 480-490.

Minten, B., Reardon, T., Das Gupta, S., Hu, D., Murshid, KAS., 2016b. Wastage in Food Value Chains in Developing Countries: Evidence from the Potato Sector in Asia. In A. Schmitz, P. L. Kennedy, T. Schmitz (Ed.) Food Security in a Food Abundant World. Frontiers of Economics and Globalization (Book 16). Emerald Group Publishing: 225-238.

Minten, B., Reardon, T., Singh, K.M., Sutradhar, R., 2014. The new and changing roles of cold storages in the potato supply chain in Bihar. Economic and Political Weekly, XLIX (52), December 27, 98-108.

Minten, B., Reardon, T., Sutradhar, R., 2010. Food Prices and Modern Retail: The case of Delhi. World Development, 38(12), 1775-1787.

Minten, B., Tamiru, S., Stifel, D., 2014b. Structural transformation in cereal markets in Ethiopia. Journal of Development Studies, 50(5), 611-629.

Minten, B., Tamiru, S., Engida, E., Tadesse, K., 2016. Transforming staple food value chains in Africa: The case of teff in Ethiopia. Journal of Development Studies, 52(5), 627-645.

Neven, D., Reardon, T., Hernandez, R.A., Tembo, G., 2017. Smallholder farmer participation in modernization of a food system: The dairy value chain in Zambia. Rome: FAO.

Pingali, P., 2006. Westernization of Asian diets and the transformation of food systems: implications for research and policy. Food Policy 32(3), 281–298.

Poapongsakorn, N., 2012. Livestock industrialization in Asia: Growth, scaling up, competitiveness and outlook for smallholders. In Asian Livestock: Challenges, opportunities, and response. Proceedings of an international policy forum held in Bangkok 16-17 August.

Qanti, S.R., Reardon, T., Iswariyadi, A., 2017. Triangle of linkages among modernizing markets, sprayer traders, and mango-farming intensification in Indonesia. Bulletin of Indonesian Economic Studies, 53(2), 187-208. http://dx.doi.org/10.1080/00074918.2017.1299923

Popkin, B.M., Reardon, T., 2017. Obesity and the food system transformation in Latin America. Report for FAO Regional Office of Latin America and the Caribbean, November.

Popkin, BM. 2014. Nutrition, agriculture and the global food system in low and middle income countries. Food Policy, 47, 91-96.

Reardon, T., 2015. The Hidden Middle: The Quiet Revolution in the Midstream of Agrifood Value Chains in Developing Countries. Oxford Review of Economic Policy, 31(1), 45-63.

Reardon, T., 1993. Cereals Demand in the Sahel and Potential Impacts of Regional Cereals Protection. World Development, 21 (1), 17-35.

Reardon, T., Barrett, C.B., Berdegué, J.A., Swinnen, J., 2009. Agrifood Industry Transformation and Farmers in Developing Countries. World Development, 37(11), 1717-1727.

Reardon, T., Berdegué, J.A., 2002. The Rapid Rise of Supermarkets in Latin America: Challenges and Opportunities for Development. Development Policy Review, 20 (4), 317-34.

Reardon, T., Berdegué, J.A., Echánove, F., Cook, R., Tucker, N., Martínez, A., Medina, R., Aguirre, M., Hernández, R.A., Balsevich, F., 2007. Supermarkets and Horticultural Development in Mexico: Synthesis of Findings and Recommendations to USAID and GOM, Report submitted by MSU to USAID/Mexico and USDA/Washington, August.

Reardon, T., Chen, K.Z., Minten, B., Adriano, L., Dao, T.A., Wang, J., Das Gupta, S., 2014c. The Quiet Revolution in Asia's Rice Value Chains, Annals of the New York Academy of Sciences, 1331, 106–118.

Reardon, T., Chen, K.Z., Minten, B., Adriano, L., 2012b. The Quiet Revolution in Staple Food Value Chains in Asia: Enter the Dragon, the Elephant, and the Tiger. Manila: Asian Development Bank and IFPRI, December.

Reardon, T., Codron, J.-M., Busch, L., Bingen, J., Harris, C., 2001. Global Change in Agrifood Grades and Standards: Agribusiness Strategic Responses in Developing Countries. International Food and Agribusiness Management Review, 2 (3/4): 421-435.

Reardon, T., Henson, S., Berdegué, J.A., 2007b. 'Proactive Fast-Tracking' Diffusion of Supermarkets in Developing Countries: Implications for Market Institutions and Trade. Journal of Economic Geography, 7(4), 1-33.

Reardon, T., Matlon, P., Delgado, C.L., 1988. Coping with Household-level Food Insecurity in Drought-Affected Areas of Burkina Faso, World Development, 16 (9), 1065-1074.

Reardon, T., Stamoulis, K., Pingali, P., 2007b. Rural nonfarm employment in developing countries in an era of globalization. Agricultural Economics, 37 (s1), 173-183.

Reardon, T., Swinton, S., Zilberman, D., 2017. The Rapid Rise of Robots in the Food System. Michigan State University, Department of Agricultural, Food, and Research Economics, Staff Paper 2017-09.

Reardon, T., Timmer, C.P., 2014. Five Inter-Linked Transformations in the Asian Agrifood Economy: Food Security Implications. Global Food Security, 3(2), 108-117.

Reardon, T., Timmer, C.P., 2012. The Economics of the Food System Revolution. Annual Review of Resource Economics, 14, 225-264.

Reardon, T., Timmer, C.P., Barrett, C.B., Berdegue, J.A., 2003. The Rise of Supermarkets in Africa, Asia, and Latin America. American Journal of Agricultural Economics, 85(5), 1140-46.

Reardon, T., Tschirley, D., Dolislager, D., 2014d. The rapid transformation of the food economy of Africa. Speech for the Bill and Melinda Gates Foundation Grand Challenges Meeting, October 6, Seattle.

Reardon, T., Tschirley, D., Dolislager, M., Snyder, J., Hu, C., White, S., 2014b. Urbanization, Diet Change, and Transformation of Food Supply Chains in Asia, Report for USAID Michigan State University Project of the Global Center for Food System Innovation and the Food Security Policy Innovation Lab, May.

Reardon, T., Zilberman, D., 2017. Climate smart food supply chains in developing countries in an era of rapid dual change in agrifood systems and the climate. Chapter in L. Lipper, N. McCarthy, D. Zilberman, S. Asfaw, G. Branca (ed.) Climate Smart Agriculture - Building Resilience to Climate Change. New York: Springer.

Rello, F., 1996. Rural nonfarm employment in Zamora, Mexico. Report to FAO Rome. Mexico City: UNAM.

Reyes, B., Vásquez, Larosa, F., Gómez, L, Espinal, M., Wiegel, J., van Loosen, I., Jäger, M., Rodríguez, I., Lundy, M., 2016. Traditional markets for poverty reduction and food security: Exploring policy options in Honduras and Nicaragua. Policy Brief no. 29, Cali: CIAT.

Schneider, M., 2011. Feeding China's Pigs: Implications for the Environment, China's Smallholder Farmers and Food Security. Minneapolis, Institute for Agriculture and Trade Policy.

Senauer, B., Sahn, D., Alderman, H., 1986. The effect of the value of time on food consumption patterns in developing countries: evidence from Sri Lanka. Am. J. Agric. Econ. 68(4), 920–27.

Sheahan, M., Barrett, C.B., 2017. Review: Food loss and waste in Sub-Saharan Africa. Food Policy 70, 1-12.

Sibhatu, K.T., Qaim, M., 2017. Rural food security, subsistence agriculture, and seasonality. PLoS ONE, 12(10): e0186406. https://doi.org/10.1371/journal.pone.0186406

Swinnen, JFM. (ed.), 2007. Global Supply Chains, Standards and the Poor. Wallingford, UK: CABI.

Swinton, S., van Deynze, B., 2017. Hoes to Herbicides: Economics of Evolving Weed Management in the United States. The European Journal of Development Research, 29(3), July, 560-574.

Timmer, C.P., 2015. The Dynamics of Agricultural Development and Food Security in Southeast Asia: Historical Continuity and Rapid Change. in I. Coxhead (ed.), Routledge Handbook of Southeast Asian Economics, London: Routledge, 89–113.

Timmer, C.P, Block, S., Dawe, D., 2010. Long-run Dynamics of Rice Consumption, 1960-2050. chapter 1.6 in S. Pandey, D. Byerlee, D. Dawe, A. Dobermann, S. Mohanty, S. Rozelle, W. Hardy (ed.). Rice in the Global Economy: Strategic research and policy issues for food security. Los Baños: International Rice Research Institute: 139-174.

Tschirley, D., Kondo, M., Snyder, J., 2016. Chapter 3: Downstream Report. in A. Allen, J. Howard, M. Kondo, A. Jamison, T. Jayne, J. Snyder, D. Tschirley, KF Yeboah. Agrifood Youth Employment and Engagement Study. The MasterCard Foundation and Michigan State University.

Tschirley, D., Reardon, T., Dolislager, M., Snyder, J., 2015. The Rise of a Middle Class in Urban and Rural East and Southern Africa: Implications for Food System Transformation. Journal of International Development, 27(5), 628-646.

United Nations. 2011. World urbanization prospects: The 2011 revision - Highlights. United Nations, Economic and Social Affairs, New York.

United Nations. 2014. World Urbanization Prospects, 2014. New York: United Nations.

Weatherspoon, D.D, Reardon, T., 2003. The Rise of Supermarkets in Africa: implications for agrifood systems and the rural poor. Development Policy Review, 21(3), 333-355.

Zhang, X., Hu, D., 2014. Overcoming successive bottlenecks: The evolution of a potato cluster in China. World Development, 63, 102-112.

Zhang, X., Yang, J., Reardon, T., 2017. Mechanization outsourcing clusters and division of labor in Chinese agriculture. China Economic Review, 43, 84–195.

Zheng, Y., 2013. Corn overtakes rice as leading foodstuff, China Daily; April 11. http://www.chinadaily.com.cn/bizchina/2013-04/11/content_16393116.htm

Zilberman, D., Lu, L., Reardon, T., 2017. Innovation-induced food supply chain design. Food Policy. In press. http://dx.doi.org/10.1016/j.foodpol.2017.03.010

Zilberman, D., Zhao, J., Heiman, A. 2012. Adoption versus adaptation, with emphasis on climate change. Annu. Rev. Resour. Econ. 4(1), 27-53.

Table 1: Domestic food supply quantities (approximation of consumption by disappearance) & composition in millions of tons & population			
	1970	1990	2013
Africa food supply quantity (ton/capita/yr)	0.46	0.49	0.59
population (in millions)	339m	581m	995m
Africa total domestic food supply	156	285	587
Imports into Africa, tons (share of total domestic food supply)	11 (7%)	42 (15%)	123 (21%)
Exports from Africa, tons (share of total domestic supply)	17 (11%)	15 (5%)	39 (7%)
Staples: cereals (% total)	44 (28%)	84 (29%)	150 (26%)
Staples: roots & tubers (not potato) (% total)	34 (21%)	53 (19%)	116 (20%)
Non-staples (% in total)	79 (50%)	148 (52%)	320 (55%)
Asia food supply quantity (ton/capita/yr)	0.37	0.43	0.65
population	2.07b	3.13b	4.26b
Asia total domestic food supply	758	1,357	2,786
Imports into Asia, tons (share of total domestic food supply)	70 (9%)	176 (13%)	507 (18%)
Exports from Asia, tons (share of total domestic supply)	30 (4%)	90 (7%)	284 (10%)
Staples: cereals (% total)	300 (40%)	507 (37%)	663 (24%)
Staples: roots & tubers (not potato) (% total)	111 (15%)	87 (6%)	70 (3%)
Non-staples (% in total)	348 (46%)	762 (56%)	2,053 (74%)
LAC food supply quantity (ton/capita/yr)	1.57	1.67	2.02
Population	284m	441m	611m
LAC total domestic food supply	447	737	1,232
Imports into LAC, tons (share of domestic supply net of exports)	15 (3%)	42 (6%)	107 (9%)
Exports from LAC, tons (share of domestic supply)	48 (11%)	84 (11%)	271 (22%)
Staples: cereals (% total)	99 (22%)	162 (22%)	230 (19%)
Staples: roots & tubers (not potato) (% total)	38 (8%)	38 (5%)	65 (5%)

Non-staples (% in total)	310 (69%)	536 (73%)	937 (76%)

Added references

Sibhatu, K.T., Qaim, M. (2017). Rural food security, subsistence agriculture, and seasonality. *PLOS ONE*, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0186406

Highlights

- The food system is the dendritic cluster of R&D value chains and the value chains linking input suppliers to farmers, and farmers upstream to wholesalers and processors midstream, to retailers then consumers downstream.

- Developing regions' (Africa, Asia, and Latin America) food systems have transformed very rapidly in the past several decades. Urbanization has been rapid, supply chains have grown long, diets have transformed deeply, structural changes have occurred both with consolidation (such as the rapid rise of supermarkets) and proliferation of small and medium enterprises (SME's) in the midstream of the value chains.

- Technology change, and the R&D systems that support it, have been extremely important to the transformation of food systems in developing regions. This has been equally important and innovative both at the farm and farm inputs level, and in the post-harvest segments.

- The transformation of food systems has been accompanied by lower food prices to poor consumers, low waste in long supply chains, increased vulnerability to shocks such as from climate and energy costs, and higher incomes and greater market opportunities for farmers who have been able to participate. It remains that low asset resource poor farmers are still challenged to diversify production and meet cost and quality and safety requirements of the developing urban markets.

- The implications for agricultural research are that IARCs and NARS should invest in understanding the whole food system and its transformation, and take it into account in adapting their strategies, plans, and choice and design of innovations in technologies and products. The supply chain is needed to implement upstream innovations, and thus the private sector, small and large, are key implementation actors for research innovations. Finally, the public research community needs to understand the importance of research on the off-farm components of the food system. Research on and productivity of processing, packaging, logistics, and commerce technologies have equal weight in the performance of the food system relative to the farm sector.

ABSTRACT. Developing regions' food system has transformed rapidly in the past several decades. The food system is the dendritic cluster of R&D value chains, and the value chains linking input suppliers to farmers, and farmers upstream to wholesalers and processors midstream, to retailers then consumers downstream. We analyze the transformation in terms of these value chains' structure and conduct, and the effects of changes in those on its performance in terms of impacts on consumers and farmers, as well as the efficiency of and waste in the overall chain. We highlight the role of, and implications for agricultural research, viewed broadly as farm technology as well as research pertaining to all aspects of input and output value chains.

Rapid transformation of Food Systems in Developing Regions: implications for agricultural research strategies

1. Introduction

The "food system[1]"has transformed enormously over the past 50 years, with the main part of the most rapid change only in the past 25 years. It shifted from being a traditional system to a mix of transitional and modern. From a historical perspective, the transformation was abrupt, not gradual. Reardon and Timmer (2014), illustrating with Asian evidence, explain the sudden change as a function of a "confluence" of "five interlinked transformations." They group them into three sets:

- Downstream demand side change, "pulling" system transformation: (1) urbanization; (2) diet change;
- Midstream/downstream change, "intermediating" system transformation: (3) food supply chain change in retail, wholesale, logistics, and processing;
- Upstream change, "feeding" system transformation: (4) intensification of farming; (5) farm input supply chain change.

Our paper extends the above work by comparing these transformations mainly in the past 25 years in Asia, Africa, and Latin America. We further include attention to the role of and lessens for agricultural research[2] strategies. We address four questions:

[1] The food system is the set of input and output value chains that link input suppliers to farmers, and farmers upstream to wholesalers and processors midstream, to retailers then consumers downstream.

[2] Note that here "agricultural research" includes both research on the inputs and farm segment (breeding, input design, agronomic practices, and so on) and research on the off-farm post-farm segments (on technologies and organization of processing, packaging, logistics, wholesale, retail).

(1) How are food systems transforming?

(2) How have research (mainly to develop new technologies in the farm segment as well as post-farmgate and input supply segments of the food system) and non-research factors (urbanization, income growth, diet change, policies) influenced food system transformation?

(3) What have been the effects of the food system transformation on consumers and on incomes of small and medium farmers, as well as system performance measures such as supply of affordable and safe and quality food, and efficiency and waste in the chains? By chain-rule logical extension, we thus examine how research affects consumers and farmers via the "pathways" of food system transformation.[3]

(4) What are the implications of the transformation of the food system for agricultural research strategies?

Our findings lead to the two main messages of the paper.

First, the farm-focused research community needs to take into account the entire food system and its transformation in their research strategies. This will determine whether innovations in farm technology and products lead to profitable marketed output by farmers and thus ultimately whether farmers will have the incentive to adopt new technologies. In the medium run, the urban market, and the food industry firms that increasingly mediate access to it, and input supply chains, and agribusiness firms that increasingly determine their development, set the market incentives and conditions for the affordability and profitability of new farm technologies.

Second, the research community needs to understand and act on the importance of processing and logistics and wholesale (of outputs and inputs) in the food system, and research on these off-

[3] That is the terms of reference for this paper for the Special Issue.

farm components of the food system. Research on and productivity of technologies for input manufacture and output processing, packaging, logistics, and commerce have equal weight in the performance of the food system relative to the farm sector. Investment in research and development (R&D) value chains for these segments needs a much higher profile in the context of the transformed food system where off-farm segments occupy 40-70% of value added and costs.

To address the research questions and justify those two messages we face two challenges.

First, unlike other pathways (examined in this special issue) of the impacts of research on farmers and consumers, such as breeding research on farm yields, it is particularly complex to examine research impacts on food systems and thence on farmers and consumers. Research is just one of the conditioners of the transformation and its impacts. We thus have to put an emphasis on discussing the transformation itself and positing impacts of research in combination with other factors (such as demand side forces like urbanization) on the transformation and the impacts of the latter on farmers and consumers. There are some empirical tests but much of the argumentation will need to rely on causal association by inference and cases, for research effects on transformation.

Second, as food system transformation in these regions is relatively recent, and the great majority of studies have been on the farm sector (as a holdover from the conventional wisdom extant decades ago when the food system was highly dominated by the farm segment and local traditional markets), empirical evidence on the transformation of the off-farm segments of the food system (input supply chains, output wholesale, processing, logistics, retail) is relatively limited and emerging and incomplete. We do our best to find and survey the key evidence, and suggest where it is strongest and weakest.

The paper proceeds as follows. Section 2 lays out an illustrated conceptual framework linking research and non-research drivers of pathways (transformation of the food system), and thence on system performance. Section 3 lays out "downstream" drivers of overall food system transformation – urbanization, income growth, diet change, policies. Section 4 examines trends in the transformation of the structure, and Section 5, in the conduct (including technology change) of the food system. Section 5 discusses emerging evidence of the performance of the transforming food system, regarding waste, food supply costs and quality, and actor incomes. Section 6 concludes with implications for agricultural R&D strategies.

2. The Food System as Dendritic

The food system can be thought of as a "dendritic" system linking input supply chains and output supply chains. The agricultural research and development "supply chain" is just one of six sets of linked value chains. As an illustration let us examine the dendritic system in which a rice value chain is the central output value chain.

The first and "core" supply chain is the output, here rice, value chain. It is composed of rice farmers (using land, labor, and capital such as machines and seeds and fertilizer) producing paddy. It is collected by rural wholesalers or transporters and taken to mills where it is de-husked and polished. The rice is then taken by wholesalers to urban wholesale markets and thence to retailers.

The second and "first round feeder" supply chains, upstream in their totality from the output supply chain, are the farm input supply chains. For rice farmers these are the value chains of seed, fertilizer, and farm equipment. These in turn are fed by "second round" input supply chains further upstream, those delivering phosphate to fertilizer factories, and steel and plastic to equipment factories, and so on.

The third and "first round feeder" supply chains are those supply inputs to the post-farmgate segments of the output value chain, in a sense "laterally" into those segments. An example is the truck supply chain and fuel supply chain supplying the rice wholesale segment.

The fourth supply chain in the dendritic cluster is usually thought of as "factor markets." Those of "capital" and "intermediate inputs" we have put above in the second and third points above (for example, chicks are intermediate inputs, and a supplied machine or fertilizer is a factor input). But here in this fourth category we put land and labor. These are also supplied in a supply chain: labor is "produced" demographically, then processed (education and experience) then delivered (transport) to the worksite. Land is originally the wilds, processed as deforested and perhaps leveled and sold or rented.

The fifth supply chain is a broad set of public assets apart from agricultural research institutions. Beside infrastructural services and assets such as protection and roads for the other supply chains, government (or private services) can supply enforcement for contracts and protection for actions of supply chain actors in the other supply chains.

Sixth, feeding all the above are the research and development (R&D) supply chains which supply technology and product innovations. For instance, companies and NARS and IARCS breed new seeds which feed seed supply chains which supply paddy farms. Packaging material researchers in companies and public research centers invent new packing materials and processes (such as Tetrapak's vacuum packing) which are supplied as "technology embodying inputs" to packaging supply chains which then supply dairy processors in the dairy output value chain.

The segments in each of the above value chains, and the six value chains themselves, are intertwined in "intersectoral (or intersegment) linkages." The essential idea of linkages is that an increase in demand or supply from one segment "induces" investment in another segment or chain (Hirschman 1958). Production linkages can be upstream or downstream. An increase in coffee farm output can induce investment by firms in washing stations and roasters downstream from the farm, or upstream from the farm (say an increase in coffee farm output can induce investment by fertilizer firms wanting to sell to coffee farmers). Consumption linkages are similar but the inducement to investment comes from consumer demand at the end of the output value chain.

The induced investment can also be in the formation of an R&D supply chain cum technology or product innovation. This occurs when innovators (public or private) or entrepreneurs design and market new technologies or new products to meet demand in other value chains. For example, if supermarket chains demand shelf-stability in vegetable varieties they contract to procure, innovators can endogenously implement a vegetable breeding innovation with an agricultural R&D value chain to breed a shelf stable variety, as derived demand from farmers wishing to supply the supermarket chain.

But seen from the perspective of a given food system, there can be exogenous R&D "investment" that is not induced by factor scarcity or attribute demand in that food system. The R&D supply chain may endogenously arise in another context (another country, another product, etc.) and then present a technological innovation "exogenously" to the given food system. An example is the creation and manufacture of extruders for feed processing in the US to increase efficiency in both feed processing and feed consumption/use in the livestock sector. It might then be transferred to Bangladesh large feed mills who imported machines embodying this innovation. This would then induce a structural change in the feed supply chain in Bangladesh.

We will return to this in the conduct section as it is a common technological innovation vector in developing country food systems.

3. Transformation of Food Systems: downstream and context drivers

3.1. Meta conditioners: Income growth, policy liberalization, and infrastructure investment

There are three "meta conditioners" that encouraged and facilitated nearly all the transformations we discuss. These conditioners are themselves mutually dependent.

First, income combined with population growth in the three regions was crucial as a pull factor. Incomes rose, especially starting in the 1980s in Latin America and Asia outside the transition countries (China, Vietnam, and India) and 1990s in Africa and the transition countries. The size of the food market increased and its composition diversified as discussed below. Typically urban areas have higher incomes than rural (e.g., in ESA, Eastern and Southern Africa not including South Africa, urban income per capita is double that of rural; Reardon et al. 2014). Furthermore, household income growth tended to be correlated with women's increasingly working outside the home both in urban areas, and with a lag, rural areas. In turn, this increased the opportunity cost of time of women and led them to seek convenience – such as in processed foods, restaurants and street vendors, and supermarkets.

Second, policy liberalization and privatization occurred during the 1980s and 1990s (from the transitions in China and Vietnam, to the de-reservations in India, to structural adjustment programs in Latin America and Africa). This policy change decreased to today a tiny minority the direct role of governments in the food system. It also increased both private sector MSMEs (micro, small, and medium enterprises) that stepped into the void left by parastatals, and proliferated to meet urban market demand. It also led to the market entry of large-scale domestic and foreign firms such as processors and supermarket and fast food chains, as well as large input firms. The massive ingress of foreign companies was abetted by liberalization of the once-ubiquitous foreign direct investment (FDI) regulations in the 1980s-2000s.

Third, governments instituted large infrastructure investment programs, particularly in Asia and Latin America in the 1980s and 1990s. This reduced transaction costs and formed the foundation for food supply chain development from rural areas to the burgeoning cities and towns, and food distribution and processing within urban areas. This in turn facilitated urbanization itself. In some places in Africa (such as Ethiopia), there have also been massive road infrastructure investment programs. For example, the total length of all-weather surfaced roads in Ethiopia tripled in less than 15 years, from an estimated 32,900 km in 2000 to 99,500 km in 2013. This substantially improved connectivity of agricultural markets in the country. In 1997/98 only 15% of the population was within three hours of a city with a population of at least 50,000, a proportion that increased to 47% by 2010/11 (Minten et al. 2014).

3.2. Urbanization

The distance of the chain is determined from a procurement perspective by throughput needed and the probability of getting what is needed from close versus far. From a supplier's perspective, it is a function of the distance needed to realize a profit on the supply side investment. If sufficient effective demand is geographically close in order to cover the investment cost of farm inputs, or to maintain a high capacity utilization rate of a rural processor, then the supply chain can be short and local. Otherwise it lengthens to fulfill those conditions.

In a traditional situation, the urban share of the population is low, and the great majority of the population is in the rural area. Supply chains are thus short and local, serving villages and nearby towns in the main. Typically, as urbanization occurs, supply chains must stretch out from the cities and grow longer as the city needs a larger and larger catchment area to feed itself. Braudel (1979) paints a famous picture of the London of the 1300s feeding itself from a few local shires to the London of the 1500s requiring food supply chains stretched all over England and beyond. This same process occurred in Latin America, Asia, and now Africa, with several points salient.

First, the urban share of the population has risen vertiginously in the past half century, in waves across the regions.

(1) Latin America's urbanization was earliest, with the urban share roughly 40% in 1950, 55% in 1970, 65% by 1990, and 75% by 2010 (UN 2014).

(2) Asia's urban share was only 20% in 1960, rising to 45% on average by 2011, and projected to 60% by 2025 (UN 2011). The region average disguises substantial variation over sub-regions. UN (2014) shows 32% in South Asia, 44% in Southeast Asia, and 54% in East Asia by 2010.

(3) Africa had a 40% urban population share by 2011, up from 24% in 1970 and projected to average 48% by 2030 (UN 2011). There is a lot of diversity over the sub-regions as in Asia. UN (2014) shows Southern Africa including South Africa as having an urban share of population of 59%. Developing Eastern and Southern Africa (excluding South Africa), what we term ESA, had an urban share of 21% in 2000, 26% by 2015, and is projected to be 44% by 2050. The latter is like West Africa in 2014, at 44%. The latter figure even for

a specific sub-region masks the heterogeneity in all regions; for instance, the urban share in population in Nigeria is 50% by 2015 (Bloch et al. 2015).

Rather than being starkly different in terms of urbanization, Africa and Asia are converging on urban shares. ESA's share is close to South Asia, and West Africa's, close to Southeast Asia.

Second, the urban food market is in fact the majority food market on average in the three regions. This is because urban areas have higher incomes than rural areas, enough so to overwhelm the negative relation of income and overall food budget share noted by Engel's Law. In an Asian study of Bangladesh, Nepal, Indonesia, and Vietnam, Reardon et al. (2014b) show that while 38% of the population is urban, 53% of the (purchased) food market is urban. Even in the poorest region, ESA, 26% of the population is urban but cities consume 48% of food produced and sold in the countries (Dolislager et al. 2015).

Third, the urban food market has grown very fast in several decades – hence so has the rural-urban food supply chain. Haggblade (2011) estimates this growth at 600-800% over three decades for Africa; Reardon and Timmer (2014) have it at roughly 1000% in Southeast Asia in the same period.

3.3. Diet change

a) Rise in the share of non-cereals

As incomes rise, "Bennett's Law" (Bennett, 1954) predicts a shift toward a higher proportion of non-staples in the diet. At a system level, this means that with development (which we roughly proxy by GDP per capita), one expects disproportionate growth of the supply chains of non-staples such as vegetables and fruit, meat and fish, dairy, and edible oils. Table 1 shows this with macro data from FAOSTAT for 1970 to 2013 with shares of tons of consumption-by-disappearance.

(1) For Africa, there was only gradual change over the 43 years, with the share of cereals inching down from 28% to 26%, roots/tubers stable at around 20%, and non-staples rising from 50 to 55% - a slim majority.

(2) For Asia, the results were more dramatic: cereals were 40% in 1970, inched down to 37% by 1990, and then dropped to only 24% by 2013. Timmer (2013) and Timmer et al. (2010) use macro data on rice to show that in most Asian countries there has been a stagnant trend in rice consumption per capita, and even in some cases (country and strata and zones) a gradual decline. Roots/tubers moved from 15% to only 3% over the period. By contrast, the striking winner in the diet was non-staples, soaring from 46% to 74%.

(3) Latin American diet composition changed less during the period compared to the other two regions. This could be because a considerable part of Latin America's rapid development occurred in the 1960s-1970s, two decades earlier than most of Africa and Asia. So that even by 1970, staples were only 30% of Latin American consumption, and that share had only dropped to 24% by 2013.

Recent micro level survey data on household food expenditures corroborate the above macro figures, and allow us to distinguish urban and rural, richer and poorer.

For Asia, Reardon et al. (2014b) analyzed household survey data (LSMS) from 2010 and found that that for South Asia (Nepal and Bangladesh) and Southeast Asia (Indonesia and Vietnam), the share of cereals (mainly rice) in the food budget in value terms was about 26% for urban and 37% for rural households. Government of India (2010) showed that the share of cereal in the urban diet (in value terms) dropped from 36% in 1972 to 23% in 2006. In the same period, the share of cereals in rural diets dropped from 56% to 32%. Despite average income differences between the South Asian sample and the Southeast Asian sample, the shares of cereals in urban food budgets were similar (29% in South Asia and 23% in Southeast Asia). Meat and fish averaged 30% of the urban budget – itself equal to the grain share. Horticulture products averaged 15%. Together meat/fish and horticulture average 45%, more than grains all together.

LSMS survey findings belie the idea that Africa is sharply different from Asia in food trends. For ESA urban and rural areas, Dolislager et al. (2015) found for Malawi, Tanzania, Uganda, and Zambia, that the share of grains (mainly maize) in urban food expenditure (in value terms) was 34%, and rural, 39%. The share of non-grains in urban food expenditure was 66%, and rural, 61%. Interestingly, they found the patterns for the poor stratum were not that different from the other strata.

For West Africa urban areas, Hollinger and Staatz (2015) analyzed data from urban food expenditure studies. Where the main staples are grains alone (Burkina Faso, Mali, and Senegal), they found that the share of grains in diets in value terms increased some over several decades: from 33 to 38%. Thus two-thirds of consumer expenditure is on non-grains. Animal products and fish are the foremost items in this set: in the 2000s they formed a quarter of total food expenditure. Fruits/vegetables average another 12% (compare that with 16% in Asia and the US), so meat plus horticulture products equal grain expenditure in the urban Sahel.

They found that for the countries where grains plus roots/tubers are the staples (Cote d'Ivoire, Ghana, and Nigeria), the share of grains dropped from 27 to 23% and tubers/roots rose from 14 to 17% over the 1990s to the 2000s. The share of non-staples (neither grains nor roots/tubers) was about 60%. Again meat/fish was found to be 21% of expenditure, and horticulture products, 17%: together (38%) they have nearly the share of staples (grains and roots/tubers), 40%.

(b) Shift of the diet toward (purchased) processed products

Research in the 1980s-1990s examined the incipience of processed food purchase in developing regions. It was driven by a new era of income increases and emerging urbanization. Processed food was seen as a time-saver for women whose opportunity cost of time increased as they entered the labor force outside the home. The emergence of the shift was shown in Latin America (Amat y Leon and Curonisy, 1981, Peru; Sri Lanka (Senauer et al. 1986); Cote d'Ivoire (Bricas and Muchnik, 1985 for West Africa; Kennedy and Reardon 1994 for East Africa).

There has been a revival and broadening of interest in urbanization and food systems in the 2000s. This occurred with the confluence of ease of import of processed foods and substantial FDI in processing as well as domestic investment in the 1980s and 1990s. Recent work has shown that its penetration is now substantial, in Asia (e.g., Pingali 2007) and in both urban and rural Africa and Asia (e.g., Tschirley et al. 2015 and Reardon et al. 2014b, respectively).

It is often thought in Africa that the processed food is imported as final manufactured items. Several recent studies test that hypothesis and reject it. For Nigeria, Liverpool-Tasie et al. 2017 found that while imported processed goods dominate in numbers of types of products, they are a minority in retail volume terms. Of course, a number of these products depend at least partially on imported raw materials such as flavorings, wheat, and milk powder.

In the ESA study of Tschirley et al. (2015), 56% of urban household food expenditures (in value terms) went to processed foods, and for rural households, 29%. In the Asia study of Reardon et al. (2014b), urban households were found to dedicate 73% of food expenditures to processed foods, and rural areas, 60%. This did not differ much over middle class versus poor families in the African and Asian studies: the quest of convenience in the face of opportunity costs of time dominated for both. It is interesting that in processed food penetration so far, rural Asia is like urban Africa, and that both Africa and Asia are tending in the same direction.

(c) Shift of the Product Composition among grains, micro evidence

Changes in diet have occasioned three types of shifts among grains.

First, the surge in demand for livestock products has translated into the precipitous rise of demand for maize as a feed grain. A striking example is that maize had been half of the tonnage of rice in 1993 but by 2013 overtook rice in production in China (Zheng, 2013). As in the US, nearly all maize in China goes into feed for animals. In Bangladesh, the aquaculture domestic supply chain grew in volume 25 fold in three decades (nearly all for the domestic market); this led to a massive rise in the feed industry and demand for feed grains (Hernandez et al. 2017). Liverpool-Tasie et al. (2016) show that the maize-based feed industry grew 600% in the past 10 years as derived demand from the aquaculture and chicken sectors that have recently started a rapid shift to the use of feed in Nigeria.

Second, the rise of demand for convenience foods by consumers has as a derived demand a rapid rise in wheat and rice as non-traditional grains for processed products. In Asia areas where rice traditionally reigned, wheat has made inroads in the form of noodles and bread (Senauer et al. (1986), for Sri Lanka; Pingali (2007) for Asia overall). Timmer (2013) shows for Southeast Asia that wheat imports into Southeast Asia rose from 1 million tons in 1961 to 13 million by 2010, and wheat consumption from 2.8% to 11.5% that of rice.

In East Africa, the rise of wheat consumption has also been driven by convenience food demand (Kennedy and Reardon 1994) as in Southeast Asia. In West Africa, there has been a rise of wheat and rice in consumption for similar reasons (Reardon 1993; Hollinger and Staatz, 2015). Wheat consumption in West Africa has also started to rise not just via the half century old luxury of bread for the middle class, but now as cheap fast noodles and bread sandwiches for the poor. An example is the rapid spread of the Indonesian multinational Indofood's "indomie", a packaged (wheat) ramen noodle, produced by Indofood FDI in Nigeria, that appears ubiquitous in Nigeria (cooked often with egg, and thus a fillip to egg consumption) (Liverpool-Tasie et al. 2016b).

Due to this shift to rice and wheat for convenience, some countries' governments have been pursuing "import substitution" drives for grains, such as recommended by African Development Bank (2016). Examples include drives to be self-sufficient in rice in Senegal and "tropicalized wheat" in Nigeria (Ohimain, 2014). This follows earlier waves of similar "internalization" of exotic food species, such as in Africa where maize, introduced from meso-America, and only "took off" a century ago (McCann, 2000), or such as cassava (Nweke 1996), introduced from Brazil into Africa with a period of intense promotion and relatively sudden diffusion. It remains to be seen whether the new wave of substitution (promoting local production of tropical wheat and local rice) will also massively succeed in the way maize and cassava where introduced.

Third, in a number of countries there is a shift toward what consumers perceive as higher quality grains. For example, in Bangladesh, there is a shift toward higher quality rice (away from coarse rice toward more fine rice). This has had implications for the milling sector (they are doing more rice polishing) and for farmers from whom wholesalers and millers are demanding the higher quality varieties (Minten et al. 2013). In Ethiopia, there is a shift away from the cheap red teff to the more expensive and preferred white teff. This increasing shift in intra-cereal demand drives changes in the portfolio of farmers (Minten et al. 2016).

4. Structural change in the food system

4.1. Stages and waves of structural change of the food system

As an initial qualifier, note that in a dendritic food system at any moment some value chains may be in one stage while others in another. Moreover, there has been, as one would expect, a lot of variation in the timing of take-off and speed and stage of transformation of food systems across products, across regions, and across countries within regions, and across zones within countries. The classifications we discuss below are found in different distributions (discussed further in subsequent sections) across the heterogeneous sets of developing countries.

We observe three stages of structural and conduct change of the food system.

(1) The least advanced stage is the "traditional" system. This tends to be spatially short ("local") and fragmented in structure, using technologies with little capital and much labor, with no contracts or formal standards, and spot markets linking all segments.

(2) The next stage is the "transitional." It is spatially long (as cities grow and their catchment area is larger and larger) but still fragmented. Chain actors use a mix of labor-intensive and capital intensive technologies. There are emerging public standards of quality. But still spot market relations dominate.

(3)The most advanced stage is "modern." It also is usually spatially long. But it is consolidating in a number of segments (such as in retail, the rise of supermarkets). There is also some "dis-intermediation" such as supermarkets buying directly from processors, or urban wholesalers directly from farmers. Private standards are emerging, and some use of contracts. Capital intensification is common as the modern stage tends to coincide with higher wages in an economy and more quality and safety control are demanded by the food industry.

The second set of stages is the waves of diffusion of food system transformation over space and products. The first wave was the earliest group of developers in developing regions (after the earlier waves of transformations of food system in what are now the "developed countries").

(1)The first wave included East Asia outside China (such as South Korea) and South America such as Brazil, with food system transformation taking off in the 1980s.

(b)The second wave was in Mexico and Central America and in parts of South America (such as Colombia, Chile), Southeast Asia outside "transition" countries, and South Africa (with the take-off starting in earnest in the 1990s).

(c)The third wave, taking off mainly in the 2000s, includes the "transition" countries, China and Vietnam, and India, South American countries "catching up" such as Peru and Bolivia, and parts of Africa especially in southern and eastern Africa.

The fourth wave that is emerging in the 2010s includes West Africa.

There are also waves of diffusion of transformation by product category, with grains value chains transforming earliest, animal products next, and fresh fruits and vegetables last. (These waves are similar to the pattern of diffusion of change in Europe and US food systems earlier.)

4.2. **Dimensions of Structural change in food systems**

The structure of the food supply chains in the developing regions has been transforming rapidly, especially in the past two decades. By structural change of the food system we mean the following, which also serves as a preview of the section's structure:

(1) volume growth in the overall system;

(2) product composition change of the system;

(3) spatial elongation of the value chains, including growth in rural to urban, rural to rural, and urban to rural supply chains;

(4) restructuring of the overall system, including an increase in the share of post-farmgate segments as well as emerging “disintermediation”;

(5) concentration or de-concentration of individual segments.

We treat each of these important changes in turn.

4.2.1. Volume growth in the overall system

Food volumes grew a lot from 1970 to now with the steepest increase from 1990 to 2013 (the latest year in FAOSTAT). This pattern roughly tracks the path of “economic development.” For simplicity we equate the latter with average income growth. Note that food volumes increased a lot at the same time there was a reduction of agriculture in total GDP, as expected from Engel’s Law.

Table 1 shows “food supply quantities” from FAO food balance sheets for 1970, 1990, and 2013. These figures are FAO’s measure of “domestic consumption by disappearance” per capita, that starts with aggregate production, adds imports, and deducts disposal of the output (exports, waste, storage for the next year, and use as seed). We then use their population data to derive aggregate consumption by disappearance per region. This is a rough measure of the food system expansion as it is only in physical terms, not value or nutrition terms. A physical measure probably underestimates growth in value terms as non-staples, which grew the fastest, have higher prices on average than grains or roots/tubers. But our goal here is not fine precision but orders of magnitude and key trends. Several points emerge.

First, in 43 years, the total "food system" in these three developing regions grew from about 1.3 to 5 billion tons, 4-fold, faster than population grew (from 2.6 to 6.5 billion, 2.5 fold). Interestingly, the trends did not differ much over the three regions.

(1) Africa's food volume expanded 1.8 times in the first two decades and then 2.1 times in the following 25 years, hence 3.8 times over 45 years. Output increase just kept pace with population 1970-1990, and then from 1990 to 2013 the ratio was 1.2.

(2) Asia's total food supply rose 1.8 times in the first 20 years and then 2.1 times in the next 25 years, for overall growth of 3.8 times in 43 years, about the same as Africa. In per capita terms, it grew 1.2 times from 1970 to 1990, and then 1.5 times in the next 25 years.

(3) Latin America's total food supply in tons rose 1.7 times in the first 20 years and then again 1.7 times in the next 25 years, for overall growth of 2.8 times in 45 years. In per capita terms, it grew 1.1 times from 1970 to 1990, and then 1.2 times in the next 25 years.

Second, imports as a share of food supply (net of exports) has risen over the decades, but is still a minority. In Africa, tons of imports rose 11 times over the 45 years – and constituted from 7% to 15% to 21% of our rough measure of consumption by disappearance. In Asia, it rose 7 times in tons and went from 9% to 13% to 18% of total consumed tons. In Latin America, it rose 7 times in tons but again a small share: from 3% to 6% to 9%. Africa and Asia's import growth occurred steadily over the whole half century. Already in the late 1980s and early 1990s it was entering the debate as a trend driven by income increases and urbanization and women's opportunity cost of time driving demand for convenience foods and thus rice and wheat imports (see for example Reardon 1993). It has continued in the African debate (African Development Bank 2016).

Third, agricultural exports, while often important in policy debates, are relatively small compared with the domestic food system. In Africa, these reached about 7% of the level of domestic consumption; in Asia, 10%; in Latin America, 22%. It was especially in Latin America that exports rose in the well-known story of its export success in the globalization period.

4.2.2. Product composition change of supply side of the system

Given that imports are a minor share of food availability, one would expect supply composition changes to roughly follow diet change. This has the following supply side impacts.

First, the overall volume growth over 43 years plus product composition change in the diet has meant huge growth in the volumes of the product supply chains themselves, especially in non-staples; per Table 1, 340% in cereals volume, 400% in non-staples; in Asia, 220% in cereals, 590% in non-staples; in Latin America, 230% in cereals, and 300% in non-staples.

Second, the rapid demand growth for meat and fish created a concomitant surge in feed supply chains, and derived from them, supply chains for domestic ingredients for feed, especially of maize (such as from Northern to Southern Nigeria), oilseed cake, fodder, rice bran, cassava. These supply chains quickly form and grow as rapid growth in animal products consumption is combined with a shift from grazing or open capture to feed based systems.

Fourth, the demand shift to processed foods created a surge in supply chains of processed products, both for low-processed products such as maize meal or polished rice, and high and ultra-processed products, such as potato or banana chips and noodles.

4.2.3. Spatial elongation & reconfiguration of the system

(a) Immense growth of rural to urban food supply chains

As noted above, roughly 50-75% of domestic food supply now goes to cities. This is very different from the 1970s when that share was roughly 20-30% depending on the region. When the urban share was low, supply chains were short, with local farmers feeding themselves and local villages and towns. As the urban share rose, and the cities got bigger, supply chains stretched further and further to fulfill the enormous needs of the cities. As domestic supply chains surge to feed cities, several points stand out.

First, seen from the countryside, most food goes to cities. About 75% of Indonesian mangoes are sold to Indonesian urban consumers; another 5% is home-consumed, and 20% are sold to rural consumers; only 0.1% are exported (Qanti et al. 2017). In ESA, the least urbanized and poorest region, 46% of cereal consumption (home-consumed by farmers and purchased by rural and urban households) is consumed in urban areas; 61% of purchases of cereal are in urban areas. In overall consumption, urban is 52% of fruit and vegetables, 58% of meat and fish, and 63% of edible oils (Reardon et al. 2014b).

Second, the product categories growth plus the rise in the share of urban consumption in total national consumption noted above together yield the result that one can double or triple the product category volume growth rates to get a rough idea of how much the volume of rural-to-urban supply chains increased. For instance, for Africa, this means that non-staple rural-urban supply chains increased about 800 to 1000% (depending on the sub region) over the past 45 years. That figure is about 1800% for non-staples in Asia. These enormous climbs represent a major investment by actors along the supply chain from farmers to urban retailers and wholesalers.

(b) Rural-to-rural and urban-to-rural supply chain growth

Even rural markets are developing fast.

First, the rural market has grown a lot simply based on rural population growth. In Africa over three decades, rural population grew 2.8 fold from 0.37 billion in 1970 to 1.05 billion in 2011 (UN 2011). In Asia, the comparable figures are rural population growth two fold from 2.1 billion in 1970 to 4.2 billion in 2011.

Second, the increase in the rural market in value terms is of course greater than what just population growth shows, for there is abundant evidence that rural incomes have grown over several decades – with of course a lot of variation over rural areas. There is also evidence that even in the poorest regions, a middle class has emerged in rural areas; Tschirley et al. (2015) demonstrate that 55% of the middle class in the ESA is in rural areas.

Third, rural purchases of food are now very important. The traditional situation was one of farm households being either self-sufficient or buying a little of their food. While early work such as Mellor (1976) in India and Reardon et al. (1988) in Africa pointed out that a lot of rural households, even farmers, are net buyers of grains, the share of overall food that was purchased was traditionally low. This of course differed by semi-arid versus more humid areas, such as in Senegal, where purchases of food were important for the drought prone areas and much less important in the relatively lush areas (Kelly et al. 1993).

But recent data show high shares of purchased food in rural diets in Africa and Asia. In ESA, Dolislager et al. (2015) show rural households bought 44% (in value terms) of food they consume. The share is 70% in Nigeria (Liverpool-Tasie et al. 2016). In the Reardon et al. (2014b) study of Bangladesh, Nepal, Indonesia, and Vietnam, rural households averaged 73% for the purchase share of their food (in value terms).

Fourth, it appears that this skyrocketing of food purchases by rural households is financed mainly by rural nonfarm employment (RNFE) as well as by agricultural product sales. Very little is purchased on credit, whether from informal or formal sources (Adjognon et al. 2017, for Africa). RNFE is roughly 40% of farm household total incomes in Africa and Asia, and a much higher share of total cash available, and far higher than migration income or credit flows (Haggblade et al. 2007). The share can be even higher, such as in China, where the share of rural nonfarm income in total income has risen from 34% in 1985 to 63% in 2000 to 71% in 2010 (Huang et al. 2012).

(c) Consequences of longer and reconfigured supply chains for small farmers

There are several potential consequences for farmers of these spatial shifts.

First, urban markets have become the main markets facing farmers. This is an important opportunity as it presents a source of effective demand far greater than the typical rural area.

Second, however, the urban market also poses challenges in two sets of ways.

Even in the absence of modernization such as the rise of supermarkets. Urban traders seek a diverse set of zones to reduce seasonality and supply risk. They have the logistics and purchasing power at times to require that different regions compete for their procurement. This means that farmers from a given zone no longer have a "protected" local market but are competing with farmers large and small from their zone and others for the urban market. They might even be competing with foreign suppliers who sell via importers to urban wholesale markets (Reardon and Minten 2011 for India).

But as urban markets modernize with the rise of supermarkets (discussed below), the competition by a region for supplying to urban supermarket procurement centers heightens, and becomes more challenging yet with the imposition of private grades and standards. Reardon et al. (2007) and Berdegue et al. (2005) illustrate this for the cases of Mexico and Central America. Processing firms and supermarkets based in towns also tend to prefer supply regions with low transaction costs, and eschew contracting with farmers in hinterland zones (Barrett et al. 2012).

Third, a key consequence of the above is that as rural purchases grow, rural to rural and urban to rural (especially of processed food) flows increase. The latter makes the proximity of rural suppliers to secondary/tertiary cities a two-edged sword. On the one hand, the proximity brings the benefits of agglomerated upstream and downstream services in the supply chain that farmers need for profitable commercialization and intensification. On the other hand, the close-by towns are conduits for a steady flow of cheap packaged processed foods that may benefit consumers on the cost side but compete with existing or would be small enterprises in the villages (Reardon et al. 2007b). There are many examples of this, such as Indofoods packaged noodles and drinks into rural towns in Indonesia and Nigeria (Liverpool-Tasie et al. 2017b). There is also an archetypal case of ready-made tortillas or tortilla mixes coming into rural towns from urban processing firms in Mexico (Rello, 1996).

Fourth, longer supply chains linking rural to urban, rural to rural, and urban to rural, means heightened vulnerability to shocks that beset long exposed chains – shocks of climate change (Reardon and Zilberman, 2017), energy cost spikes, disease outbreaks, food safety crises, and sociopolitical strife. A case in point is the vulnerability to all these represented by the dynamic south-north and north-south maize and egg supply chains in Nigeria (Liverpool-Tasie et al. 2016).

4.2.4. Change in overall structure of the system, including an increase in the post-farmgate and "disintermediation"

a) Increase in the share of the "post-farmgate" segments in the developing food system

In a local traditional short supply chain, very little of the value added of the chain is due to off-farm components of the supply chain – the midstream (wholesalers, logistics agents, processors) and downstream (retailers). The farmer sells the grain or milk to neighbors and transports it herself. The consumer buys the raw product and processes it herself.

As the chain grows spatially longer, the market volume grows large enough, and economies of specialization emerge in the midstream and downstream segments, their shares rise a lot compared with traditional chains. Reardon (2015) reviewed evidence and produced a rough estimate for Asia and Africa food supply chains of about 40% of value added from farms, 40% from midstream (what he calls the "hidden middle" as this segment is usually ignored in both policy debates and research) and 20% from the downstream. This share varies over products and regions.

b) **System restructuring with the emergence of a "Quiet Revolution" of MSMEs in the food system**

A "traditional" short local supply chain could have just the farmer selling to other villagers, or a rural broker selling to a traditional small retailer in a local town. As supply chains develop to cities, and gradually consumers purchase processed products, there is a proliferation of midstream MSMEs in wholesale and processing, as well as upstream in input supply. This is part of the "transitional stage" and is the dominant situation now in Africa and South Asia. Typically the farmer's share in the total value added of the supply chain drops fast during this period as the share of intermediaries and logistics and processors rises.

A series of recent studies in South Asia, China, Vietnam, and Africa have termed this a "Quiet Revolution" wherein tens of thousands of MSMEs emerge to develop in a "grassroots" way the food system (Minten et al. 2010; Reardon et al. 2012, 2014c). These studies show how dynamic these MSMEs are in developing the food system. Three examples intrigue.

First, there has been a rapid emergence of MSME potato cold storages in Bihar (Minten et al., 2014) and Western Uttar Pradesh near Delhi (Das Gupta et al., 2010). We focus on the latter. A survey of cold storages in Agra found that the combination of the rapid development of vegetable demand in Delhi, the improvement of the road link from Agra to Delhi, the introduction of a disease-resistant and long-shelf-life potato variety, the introduction of an electricity grid, the partial subsidizing of irrigation pumps and cold storage equipment, and the economy's generating investable funds among the intermediate city business sector, led to very rapid and deep change in the cold storage sector in Agra and, in turn, on the seasonality and cost of potatoes in Delhi and intermediation patterns in the rural area. In the early 1990s relatively few farmers grew potatoes in Agra and there were almost no modern cold storages. By the late 1990s cold storages had risen to store 40% of the vastly larger potato output, and by 2009, 80%. Traditional on-farm storage went from ubiquitous to 1% of the potato harvest. Delhi went from sharply seasonal potato consumption (from fresh harvest) to multi-season availability and 65% of consumption from cold-storage potatoes mainly from Agra. Rural brokers were sidelined by the cold storages themselves becoming the main locus of intermediation with urban wholesalers coming to buy potatoes from farmers at the storages.

Second, there has been a proliferation of "outsourced agricultural services" in the form of MSMEs providing combine services for small rice farmers in China (Zhang et al. 2017) and Myanmar (Belton 2017), and cotton farmers in Peru (Escobal et al. 2000). These are mobile teams equipped with combines go from farm to farm and province to province. They provide speedy, skilled service that compensates for small farmers' lack of the ability to buy their own machine, or the skill and time to rent their own machine. Moreover, the capacity of the machines is typically much larger than local owned or rental machines, so that the harvesting and threshing can be done quickly, and in a timely way for higher market prices before the glut. An analogous service is performed by MSMEs called "sprayer traders" in mango zones of Indonesia and the Philippines; teams of skilled laborers equipped with sprayers and vehicles and ladders go from farm to farm and prune, spray, harvest, sort, and market mangoes for demanding urban and export markets (dela Cruz et al. 2010; Qanti et al. 2017).

Third, Minten et al. (2016) show that the value chain of teff (the leading cereal in Ethiopia) has developed rapidly to serve the Addis Ababa market over the past decade. There has been a proliferation of MSME mills-cum-retailers and rapid transformation all along the supply chain. The recent development of the teff value chain was found to be driven overall by significant growth in Addis and increase in incomes (with a doubling of income and a doubling of teff expenditure in the past 10 years); by the increased opportunity cost of women's time (saving time cleaning and milling teff and making enjera (teff pancake)); by the diffusion of cell phones, improvements in roads and reduction of transport costs (in part driven by mass aggregate investment by wholesalers in trucks), and provision of teff government extension services.

The development of the teff value chain was in turn correlated with (1) increasing adoption of modern inputs (chemical fertilizers, improved varieties of seed, and herbicides) by farmers, especially by those living close to urban centers; (2) rising quality demands and important shifts from the cheap red varieties to the more expensive white teff varieties, with concomitant increases in productivity due to the uptake of improved varieties; (3) increasing consumer willingness to pay for convenience in urban areas, with the rapid emergence of one-stop retail shops that provide sales, cleaning, milling, and transport services, as well as a sizable food service industry; and (4) declining share of the margins of rural–urban marketing, urban distribution, and milling in the final retail prices of teff, indicating improved marketing efficiency over time. Traditionally, and still in rural areas and small cities and towns outside Addis, consumers buy teff as a grain, clean it at home, have it custom milled, and then prepare enjera at home. These practices have changed in Addis over the past decade, with a decline in custom milling and in cleaning grain at home. Instead, consumers are buying teff flour or enjera, driving a sharp increase (nearly 50 percent) of teff mills and retail outlets in the neighborhoods.

(c) **Disintermediation with late-in-stage transitional and modern supply chains**

As market volume and investment capacity permit large enterprises to develop (anywhere along the chains, from inputs, to farming, to wholesale, to logistics, to retail), these firms have a tendency to try to “cut out the intermediaries” and sell or buy directly. This is done mainly to cut costs. This is termed “dis-intermediation.” This is associated with the “transitional” and “modern” stages of the supply chain. For example, larger wholesalers based in towns and cities have in India gone well along the path of eliminating use of traditional village brokers in order to buy directly from rice and potato farmers (Reardon et al. 2012). Supermarkets in Central America have shifted to buying directly from agribusiness firms for crops in which the latter are engaged (e.g., pineapples, bananas) (Berdegué et al. 2005).

Supermarkets and processing companies also have a tendency for “re-intermediation” - to shift from procurement on the spot market to use, as much as possible, of specialized, dedicated wholesalers to procure and market (Reardon and Berdegué, 2002). They are charged with applying quality and safety standards of the chains or processor, selecting regular suppliers such as farmers or supplier villages or coops who can meet the standards, and collecting or marketing exclusively for the chain or processor. An example is large rice millers in China relying on specialized agents to market their branded packaged rice (Reardon et al. 2012), and supermarkets in Latin America and Africa and China using dedicated wholesalers to source produce according to the private quality standards of the chains (Reardon and Berdegué, 2002 for Latin America, Weatherspoon and Reardon 2003 for South Africa, and Hu et al. 2004 and Michelson et al. 2017 for China).

4.2.5. Per segment, de-concentration then concentration then re-concentration

In short local supply chains to small towns or rural areas, the market volume does not permit the emergence of large-scale firms. At a micro level, for a firm to attain scale, potential market sales as well as investment capacity are needed. The potential market can come from increase in scale of demand due to consumer income increases; or access to a secondary or mega city that represents large agglomerated demand. These large effective demands can be supplied by many small firms and farms. But if the technology is characterized by economies of scale, this encourages firms to invest in scale. This is typically the case with processing, and where transport and warehouse and cold chain are needed, with wholesale. As the need for coordination and inventory control rise with marketing scale, and bargaining power in procurement with buying scale, there can also be economies of scale and scope in retail.

At the segment level, if competition is only on cost (hence the “commodity” stage of the product cycle) and the large firms or farms are more efficient than the small, concentration can occur. This is often observed in the “modern stage” of supply chain development, at least for some segments. In those segments there will be concentration. In others the structure may stay fragmented for some time. For example, in the modern portion of the dairy sector in Zambia, small farms could be selling to large processors who sell some of their output to supermarkets (Neven et al. 2016). Or, in a late “transitional stage,” in long supply chains with some disintermediation (such as town-based wholesalers competing out of the market the small rural brokers, but selling on to many small urban millers and mainly small retailers; this is the case of the Bangladesh rice supply chain (Minten et al. 2013).

Reardon (2015) conceives of concentration change as a “J curve” with three stages that roughly coincide with the stages of modernization of the food system.

The first stage is the high fragmentation that characterizes the traditional supply chains. As an initial move to serve incipient urban markets and build economies of scale and obviate what are perceived as “exploitative traders”, governments sometimes introduce parastatals in this stage, especially for basic grains. These partially concentrate the wholesale and retail segments, hence providing the leftmost part of the J of concentration over time.

The second stage occurs after market liberalization and the privatization of the parastatals. The vacuum thus left, as well as the propitious logistics and demand side conditions that also induce the development of the transitional stage of supply chains (public road investments, urbanization, income increases), induce the proliferation of MSMEs in the segments of the supply chain. This is what we termed the “quiet revolution in food systems” discussed above.

The third stage is the steep rightmost part of the J, and is the re-concentration that occurs as competition among MSMEs has it that some emerge as winners and expand, and FDI liberalization and other investment regulation relaxation (such as "de-reservation" in India, Reardon and Minten 2011), induce investment by large private processing, wholesale/logistics, supermarket chains, and fast-food chains. This has involved, especially since the early/mid 1990s, waves of diffusion of supermarkets and large processors in particular (Reardon et al. 2003, Reardon and Timmer 2012). Much of this started as regional or global FDI, and then has generated intense domestic capital investments.

In the second and third stage of transformation of the food system there is "co-evolution" of the segments. In the second, "transitional," stage, there is both spontaneous private sector co-evolution as wholesalers and processors proliferate to serve the burgeoning urban retail sector. There is also conscious public intervention, as municipal governments construct public wholesale markets (witness the diffusion of those in the 1970s and 1980s in the first wave countries, 1980s and 1990s in the second wave, and 1990s and 2000s in the third wave countries, mainly in Asia such as China and Vietnam and India, but also incipiently but in a limited way in Africa).

In the third, "modern" stage, private sector coevolution is intensified and at large scale. The importance of coevolution is that it accelerates the system transformation and raises entry requirements for small firms that want to compete either in the commodity market (on cost) or in quality differentiated products. Supermarkets tend to source from large processors so as to reduce procurement transaction costs and make sure of quality and eventually food safety. An example of this is relative concentration of reliance by supermarkets in China on large scale rice mills (Reardon et al. 2012b). Large processors target product differentiation to the requests of supermarkets, such as for milk and juice products by Nestle and others in Brazil (Farina et al. 2005). Large logistic and wholesale multinationals as well as processors "follow" supermarket chains into new countries, in "follow sourcing", as with Baakavor following Tesco into China (Reardon et al. 2007).

Relative to the traditional stages, the transitional and modern stages have occasioned the most "conduct" change in the food system – with new technologies, organizational forms, and new institutions of private standards and contracts. We turn to this conduct change next.

5. Transformation of Food systems: focus on conduct (organizational, institutional, and technological) changes

5.1. Endogenous transfer, co-evolution, and innovators' strategic system design

At the risk of over-simplifying, in the past 200 years since the industrial revolution in Britain, and the agriculture technology and food system organizational revolutions in the US and Western Europe, the bulk of basic innovations occurred first in US and Western Europe and then been transferred and adapted in developing Asia, Africa, and Latin America in the past 50 years. (This is of course not to forget that that industrial revolution itself reposed on a series of innovations from much earlier mainly from East and West Asia. The compass and the horizontal loom from China serving as the basic innovations at the foundation of the mercantile and industrial revolutions in the "West" are examples enough.)

Key innovations in agriculture technology (such as chemical fertilizer, hybrid maize, tractors, pesticides, genetic modification, and so on), in processing and wholesale and transport (motorized mills, trucks, refrigeration, freeze drying, and so on), and in organization (chain stores, self-service retail, supermarkets, private standards) emerged in the US and Western

Europe as their industries and then food systems urbanized, diversified, and passed from local food systems (extremely similar to traditional food systems in developing countries now), to transitional and then recently to modern food systems.

These "West-origin" innovations were transferred and adapted in the past 50 years in the spatial and product waves we discuss above, as demand side and policy conditions grew receptive and propitious for their transfer in Asia, Africa, and Latin America. The channels of transfer included: (1) massive waves of foreign direct investment (FDI) by agribusiness, processors, logistics and wholesale, and retailers; (2) investments by local entrepreneurs and public sector in innovations from the US or Western Europe they observed in FDI activities or on a business trip or university education, or read about on the internet. Of course, not all of the basic innovations even during the 50 years were being transferred initially from the "West." For example, there was basic rice breeding innovations in and from China during that period.

The local private entrepreneurs and public sector in developing countries as well as innovating "Western" companies diffused those initial innovations, adapting and modifying them to local conditions. Just as in the "West" the initial innovations had developed as packages of inter-dependent innovations (such as the example of Tyson above where genetic variation, contracting, private standards, piecing and cooling or freezing, long distance transport, and marketing in supermarkets), the transfer of one or more innovations, in technology or organization, brought with it the cluster of other related innovations.

Zilberman et al. (2017) examine the proactive links between an innovator's innovation and his/her "implementation" of that innovation, to generate and protect an initial advantage and profit arising from the innovation's superiority (in cost or quality or safety) to the technology or product it supplants. They present the structure and the conduct of the supply chain based on that innovation, as endogenous, constructed. Again, the Tyson chicken example serves; Tyson innovated with frozen or chilled chicken parts and needed to produce these massively to be competitive and supplant frozen whole chickens sold by their competitors. The initial product cum technology innovation was "implemented" by Tyson choosing to select and impose new breeds of chicken, institute contracts with out-growers, invest in large scale centralized processing, and contract with specialized large scale logistics firms.

In that sense then, the food system changes we observe, especially in the modern phase, are emanations of the strategies of a large number of innovating companies. These strategies are sets of technologies and institutions and organizations chosen to implement the innovations. But they are also "induced" innovation in other companies to help them implement the innovation and thus also profit in a coevolution schema. An example is given below where Nestle, having innovated ultra high temperature (UHT) milk processing technologies and products in Western Europe, transferred this to large scale processing FDI in Brazil; at the same time and of course linked, Tetrapak, with its vacuum packaging innovation, set up in Brazil to provide packaging to Nestle and others (Farina et al. 2005). For efficiency of the set of UHT plus packaging plus large scale manufacture of both, farmers needed to contract with Nestle and implement private standards pertaining to levels of protein sediment, bacteria, and fat in the milk they delivered.

Understanding both the role of public research and private innovators, and the linkages between technological, organizational, and institutional innovations in developing food systems, is central to our analysis of transforming food systems. Below we explore in more detail these innovations born out as changes in the system.

5.2. Organization and institutional change

Organizational change can be analyzed in terms of “markets and hierarchies” in the words of Williamson (1981). Actors can choose to transact via the uncoordinated spot market, such as brokers coming to a wholesale market to buy and sell, or via some degree of coordinated or hierarchized market. An intermediate or transitional form could be the use by a supermarket chain of the specialized/dedicated wholesalers noted above, as agents to buy or sell, and in doing, implement its quality and safety standards and price points. A full form could be a tight contract where standards and price are specified to suppliers of the supermarket or processor, usually as a direct, disintermediated relation.

As the food system moves from traditional to transitional to modern, there is a shift organizationally from spot to transitional to fully coordinated. This tends to occur fastest in grains, oil seeds, and processed products, and next fastest in fresh meat, and slowest in fish and produce. Thus, in Mexico for example, for grains and meat one can find fully coordinated supply chains from farmers to supermarkets, with (1) branding and packaging; (2) direct purchase from suppliers or special agents, (3) distribution centers, (4) public and private standards, and (5) some contracts. But for fresh produce, one finds supermarkets relying on a mix of: (1) spot market relations in wholesale markets, (2) off-market specialized wholesalers such as Pedraza, and (3) direct contracts with large agribusinesses such as Mr. Lucky for vegetables (Reardon et al. 2007b).

Finally, linked with the above organizational change is the three-staged emergence of standards as “institutional innovations”.

First, in the early stages of commoditization in national markets and international trade, there is the gradual emergence in developing countries in the 1970s/1980s of public standards of quality (in particular of grain quality) to allow for long-distance trade with low transaction costs and risk, and then phytosanitary public standards to allow for animal and horticulture product movements over borders.

Second, with product differentiation, rise of non-staple consumption, and modernization of supply chains, private standards for quality and safety began to emerge in the 1990s and 2000s. These were especially manifest in export operations and processing sectors, with gradual emergence in perishables for supermarkets. Usually these were imposed by supermarket chains, large processors, and fast food chains, and their procurement agents, to reduce losses in processing, increase shelf life, control quality and consistency, and assure safety (Reardon et al. 1999; Henson and Reardon, 2005; Swinnen 2007). Examples include Nestle's quality certification for grated coconut in Brazil (Farina et al. 2000) and potato variety specification for French fry production by McCain's for McDonald's in Argentina (Ghezan et al. 2002).

Third, with further development of street vendors of prepared foods, formal restaurants, and fast food chains, and domestic trade in perishables, gradually governments have instituted public food safety regulations for retail and food service (for example, in China, Jia and Jukes, 2013). In some cases there is strong argument for economic and health impacts of regulation but implementation is difficult (such as in the case of aflatoxins in maize and peanuts in Africa, see Khlangwiset and Wu, 2010).

Technology innovations have been generally necessary – in every segment of the food system – to accompany and implement the structure and organizational/institutional transformations noted above. We turn to these innovations next.

5.3. Technological change per segment – upstream and midstream/downstream

In this section we discuss the technology changes that occurred as the food system transformation occurred, and thus by extension the impact of technology research in IARCS and NARS and private companies on that transformation. We start with upstream, then look downstream. Within each, we start with commoditization-facilitation technologies (that get costs down), and then go to product differentiation-facilitation technologies (that help produce other attributes like quality and safety).

5.3.1. Farm product breeding technologies and supply chain transformation

Breeding research and thus variety change have been fundamental forces in fueling the massive "throughput" of feedstock in the transforming food system. R&D supply chains for new seeds and other inputs depend critically on a combination of the development of private seed markets as well as private and public sector breeding of improved seeds to allow intensification by farms.

The contribution can be thought through along the lines of the product lifecycle in three stages: (1) the product traditionally or as the result of an innovation emerges as a "niche product"; (2) if there is scope for wide demand, firms focus on innovations for cost reduction and develop it into a "commoditized bulk product" at a much greater volume; (3) as competition drives down per unit profit, innovating firms move to the stage of "differentiated products", differentiating by variety cum quality or safety or unit size or some production attribute such as labor rights or environmental sustainability. Each of the latter is then a candidate to repeat the cycle of commoditization then differentiation.

There are two ways we can link product demand change (diet change) over a product cycle, and food system transformation, to agricultural research, in particular breeding, here. In the next section we discuss a broader range of technology change related to other aspects of supply chain change.

The first path has received the most attention, and that mostly for grains: the focus has been on breeding for drought or flooding and disease resistance and adaptation to small farmer conditions. The best known example is of course the Green Revolution and the system of NARS and IARCs that emerged to form R&D supply chains of new seeds demand by poor people who wanted and needed to intensify production on small plots (Lipton with Longhurst 1989; Hayami and Ruttan 1971, Binswanger 1978). Another example is the shift from local variety to broadly diffused commodity mainly due to agroecological adaptability crossed with breeding to make the product of increasingly wide diffusion. An example of the former is McCann's (2000) account of flint and then eventually dent maizes spreading to zones of Africa where formerly sorghum and millet had been produced. A third example of the latter is the breeding of maize to fit drier areas, such as was done by Zaria in Northern Nigeria in the 1980s (Byerlee and Eicher, 1997).

The second path links product cycle, breeding, and commoditization market development. This second path has received relatively little attention, although the little received is mostly for grains.

The first variant of this second path is intra-product. It has focused mainly on breeding for quality and processability, transport, and shelf-life/storage characteristics. A first good example of "commoditization" is the shift from traditional flint to bred dent maize in output composition as the industrial maize milling industry took off mid-1800s in the US, matching the emergence of purchased-processed foods by US consumers in the second half of the 19th century. Investment in the establishment of a maize processing industry in the second half of the 1800s "induced" a shift in the farm segment from the traditional flint maize to the new dent maize (with high soft starch better for milling than the flint varieties). At the same time, the breeding of the dent maize (by the Reids, farmers in Illinois) in the 1850s, initiated a dent maize seed industry (R&D supply chain as well as seed breeding and multiplication and sale). This "induced" a shift in the farm segment to shift from flint to dent maize. One could thus see the initial "shock" or inducement as coming from the seed segment or from the processing segment, and having linkage impacts either downstream or upstream on farms. In fact the two shocks were a confluence of changes, as the processing industry needed the dent maize attributes to be produced to spur the mill sectors' growth, and the dent seed industry needed the downstream farms and mills to demand dent maize seed and grain.

Research attention in developing countries has recently been directed to the above trend linking grain varieties, urban supply chain growth, and milling industry transformation. One example is teff variety differentiation for quality for the urban market of Addis Ababa (Minten et al. 2016). Another is a similar trend for rice varieties in Bangladesh (Minten et al. 2013).

A second good example of breeding for "commoditization" in the food system is from Goodhue and Rausser (2003). They analyzed technology change during supply chain elongation and commoditization in the broiler industry in the United States. Firms first identified the attribute consumers wanted: chilled rather than frozen chicken meat. The industry then innovated with ice-bath transport of the meat, plus genetic improvement of chickens so that meat would be less porous to water penetration and would stay chilled without becoming waterlogged. These innovations allowed broiler meat to be shipped further and thus reach a larger market. Firms coordinated with farmers via contracts specifying the use of that specific type of chicken. Goodhue and Rausser also cite a similar case with hogs. In both cases, the value chains transformed quickly in terms of technology change, the use of contracts, and market size.

A third example goes beyond commoditization and depicts breeding for product differentiation in produce supply chains. The example is kiwi fruit. Originally a local niche product in mountainous areas of China, it was then commoditized (first by New Zealand firms then by others) at a global scale, abetted by supermarket demand for year-round produce starting in the 1970s-1990s. The path was first through the diffusion of green kiwis to a number of countries (Italy, California, and even then to China as cash crop); then it was differentiated by the breeding of a sweeter "golden kiwi" by the New Zealanders, which at first was a luxury niche product and now is being diffused globally and entering the commodity phase, such as with mass plantings in California and recently in China.

5.3.2. Non-seed input supply chain technology change to support farming intensification

Supply chain development, urbanization, and local industrialization or access to imported external inputs tend to be correlated. That drives down the cost of capital inputs (irrigation equipment, seeds, fertilizer, insecticides, herbicides, tractors and combines and sprayers), inducing their diffusion. Both the private sector and NARS have been deeply engaged in R&D over the past 150 years that have had fundamental effects on the quality and cost (and existence) of these inputs. Four examples of private sector R&D cum extension supply chains creating these innovations are of interest.

First, as labor costs rose in the US and the UK in the 1940s, herbicides were created by private companies in the UK and then government and private companies in the US and were used immediately to substitute for hand weeding. This innovation quickly diffused in the US over the 1940s to the 1990s (Swinton and van Deynze, 2017). Due to increases of labor costs in developing regions, a parallel adoption of herbicides has occurred in waves similar to the system transformation waves from the 1970s to the 2010s (Haggblade et al. 2017).

Second, as demand for machine use in farming rose in the US in the first half of the 1800s as farms extensified and labor constraints appeared, the combine was invented by private parties in the US and Scotland. It diffused over the century, shifting from horse to steam to gas engine powered, with a string of innovations by companies such as John Deere. It was then adapted for small farms in the 1970s in Japan by Kubota, and from there diffused widely over developing Asia and into Africa in the subsequent decades.

Third, as demand for water in horticulture rose in Germany, Australia, Israel, and California from the 1860s to the 1960s, there were a series of innovations from clay to plastic tubing that came to be termed drip irrigation. Again, as with the innovations above, starting in the 1970s it was adapted and diffused to developing countries, innovations by companies like Netafim of Israel and then Jain Irrigation of India.

Fourth, Notore Chemicals in Nigeria are a major supplier of agro inputs. They have developed a private system for training and input distribution in rural areas which uses local entrepreneurial residents (often youth) to be their sales agent and resident extension officer for farmers in rural communities all across Nigeria (Liverpool-Tasie et al. 2015). Through this they are able to create brand recognition to address the problem of poor input quality in Nigeria while also leveraging the social capital of their sales agent to spread new technologies, learn of and meet farmers needs and enforce repayment if inputs are taken on credit.

5.3.3. Post-farmgate technology change

While the great majority of attention in the research community has been focused on farm technology change as a facilitator of food system change, technological change occurring in off-farm components of the food system - input supply chains as well as the midstream and downstream of food supply chains - is as important as farm technology for the overall performance of the food system. Recall that the midstream and downstream segments together represent roughly 60% of the food system's costs and value added.

The drivers of post-farmgate technology change are similar to the farm technology points above. As with farm technologies, a gradual increase in wage rates combined with a decrease in physical capital prices (from local industrialization and imports) induced midstream and downstream capital intensification and productive capital upgrading. Demand side factors such as demand for new products, new quality and safety attributes, and greater and more storable volumes also induced technology change.

R&D supply chains to create and deliver the new off-farm technologies (embodied in a range of quasi fixed and variable capital inputs) noted below tended to develop along with investments in the post-farm and input value chain segments. This was "induced technological innovation." These were sometimes started as basic science innovations in public research institutions and then there was a great deal of adaptation and innovation by private companies. Many were originally the inventions of individual inventors, or the fruit of R&D units of companies. Some innovations where all three of these, such as the cluster of inventions and improvements around freezers or tractors.

As noted above, as in farm technologies, much of the initial innovation occurred earlier, in currently developed countries historically, and then was transferred and adapted to developing country supply chain situations. Or, it occurred in one more advanced setting recently and then as it became possible or desirable, it was transferred to a less advanced setting. An example of this above was herbicides; invented in the US 40 years ago, recently China and India adopted them and worked up a large capacity for their production and now export them to Africa. The same can be said of vehicles; invented by Germans 130 years ago, one now sees second-hand Chinese petrol farm vehicles throughout Myanmar's food supply chains. One also sees second-generation Dutch or German milling equipment all over developing regions now. Alibaba.com sells all manner of post-harvest equipment from Chinese factories in many developing countries, much of it already adapted to smaller scale or tropical conditions by Japanese and Indian and Chinese innovations in the past two decades.

We provide several prominent illustrations below of post-farmgate technology innovation.

Logistics. Innovations and investments in logistics have been fundamental to the rapid and recent elongation of the food system and the reduction of seasonality. The teff value chain transformation research in Ethiopia (Minten et al. 2016) shows a rapid shift from transport of teff by foot (head loads) to animal transport (donkey/horses, carts), to motorized transport, and then from small trucks of 4-5 tons to truck-trailers of 20 tons – a thousand years of transport change in a decade. Systems that had been relatively local switched to long distance commerce as combinations of large trucks and train lines combined to move potatoes from Northern to Southern India, abetted by potato varieties with tougher skins to transport further and store longer (das Gupta et al. 2010). Potato supply chains grew over a few decades from remote mountain areas to large cities across China (Gansu to Beijing by truck; Reardon et al. (2012); Gansu to Shanghai and Guangdong by rail; Zhang and Hu (2014). Some innovations have been surprising: in Myanmar in 2011, bus transport was privatized and liberalized. Bus lines proliferated and competed. One way they competed was by adding an iced cold shelf in the buses for fish to be transported from aquaculture areas in the south to Mandalay in the north. This gave rise to nearly 200,000 tons of fish moved by small merchants via many buses (Belton et al. 2017).

Processing scale and agglomeration. In the shift from the transitional to modern stages, economies of scale of processing of output and feed and economies of agglomeration of farms and processing near consumption areas account for scale increase, technology change, and peri-urban agglomeration of fish, pigs, and chicken. For example, aquaculture, in an early stage in Myanmar is mainly produced near and sold in the mega city (Belton et al. 2017). A similar thing is happening with poultry and hog production in developing regions. Their initial commercial production base is in small operations around cities. These tend to shift both structurally from scattered home enterprises to larger farms and integrated operations, and spatially to from scattered rural sites to agglomerated areas near the cities. In Thailand, the share of backyard pig farms dropped from 55% to 20% of pigs over 1993 to 2008; large chicken farms have grown from 39% to 57% of chickens over the same period (Poapongsakorn 2012). In China, backyard (small-scale) pig production was 95% of the market in 1985 and 27% in 2007 (Schneider 2011). There has been a concomitant rise of large processing firms for pigs and chickens, with location of large farms and large processing firms near the cities of China and Thailand, in a major shift away from scattered countryside operations in the 1990s and before.

Freezing and Packaging. As freezing and packaging technologies are transferred and adapted and investments made, there is often an elongation of supply chains from near cities to near areas with low cost natural resources. For example, with rapid development of the frozen fish industry, fish is increasingly shipped longer distances within countries; there is a massive flow of frozen fish from aquaculture areas in the South of China to Beijing, mainly developed in the 2010s as an outgrowth of an initial export operation base (Bai et al. 2015). The same is happening with vegetables, with the rise of frozen vegetables shipped long distances (such as happened with potatoes in Argentina (Ghezan et al. 2002), and green vegetables and sweet corn in Chile (Milicivec et al. 1998).

A similar change took place in dairy in Brazil in the 1980s and 1990s. There was a combination of four internationally-transferred technology and organizational innovations that led to a massive increase in milk consumption in Brazil in the 1990s, an increase in average dairy farm size and exit of the smallest farms, and a spatial shift from peri-urban production in the 1980s to spatial concentration in cheap grain and forage zones far from the main cities in the 1990s (Farina et al. 2005):

(1) Nestle and Parmalat intensively invested in Brazil in the late 1980s after liberalization of FDI, transferring large scale processing technology;

(2) supermarket chains spread in the late 1980s and early 1990s with liberalization of retail FDI; they sought reduction of transaction costs in procurement, preferring larger milk processors, and long shelf life milk to introduce to consumers many of which did not yet have refrigerators;

(3) UHT (ultra high temperature) treatment of milk (invented in Denmark in 1910) allows it to be stored at ambient temperatures if in vacuum packed containers;

(4) the four layer vacuum packed container technology was invented in 1952 by Tetra Pak of Sweden; they invented this technology at first for the European market as milk demand had dramatically increased after WWII. Tetra Pak made it practicable to have UHT enter mass production. Tetra Pak heavily invested in packaging facilities in Brazil in the late 1980s and

1990s. This served the developing dairy and juice markets with long shelf-life packaging and vacuum packing;

(5) the result was widespread diffusion of UHT in Tetra Pak containers: Farina et al. show that UHT milks went from 10% to 90% of milk consumed in Brazil just in the decade of the 1990s.

Extrusion for feed and noodles. Demand for more processed foods induced transfer and adaptation of food processing technologies. Feed processing plants adapted new technologies for extrusion of pellets, and noodle factories, extrusion techniques. This has led to extremely rapid even sudden diffusion of pelleted, floating feed in Bangladesh aquaculture, that itself expanded 25 fold in three decades (Hernandez et al. 2017), and diffusion of Japanese study ramen noodles manufactured by Indofoods in Nigeria (Liverpool-Tasie et al. 2017).

Traceability and inventory and safety monitoring technologies. Demand for time saving in shopping induced transfer of retail "technologies" and organization, like supermarkets and chain stores. An example is the adoption of bar codes and electric scanners for inventory control. Food safety concerns among urban consumers of perishables and rural and urban consumers of maize and peanut products induced food safety cum waste control measures like pasteurization of milk, addition of aflatoxin binders in stored maize by traders and millers, and humidity measuring devices and grain driers by traders and warehouse owners.

6. Food system transformation's performance – on waste, food supply costs and quality, and impacts on actor incomes

Above we have laid out the first two of the three logical steps in this paper – to wit, the impact of research (particularly in technology), controlling for other factors like diet change, income growth, and urbanization, and food system transformation. In this section we will lay out the main elements of the third point, the impact of transformation on performance. Several points stand out.

First, it is nearly tautological that the expansion in volume of the food system, given that it is 80% domestic, has benefited small and medium farmers, as those constitute the bulk of producers for domestic markets in the three regions. Moreover, the strong tipping of the product composition toward non-staples, which are usually higher value per ton or hectare or day, mean that at least the farmers who have been able to diversify are able to gain from that shift. The literature is full of examples of medium-large net income increases of farmers shifting from grains to fish or horticulture or dairy or poultry.

Second, the available evidence shows that it tends to be the upper tier or half of small farmers who can access the urban markets and the non-grain markets, as they require placement near enough to roads, and some water access. At first the excluded must shrink as supply chains get longer and longer. But then as the chains modernize and increasingly demand quality and safety, those farmers reached must make basic investments in those attributes and that narrows the winners. The evidence shows that small farmers can still be included, but tend to not be the hinterland or asset-poor farmers (for a review, see Reardon et al. 2009).

Where food industry firms need small farmers, and the latter suffer from idiosyncratic market failures and asset constraints, with modernization, some food industry firms supply “resource provision contracts” (Austin 1981 and Gow and Swinnen 1998) that are reminiscent of the earlier tied output-credit market arrangements of traders, that are largely disappearing (for Africa case see Adjognon et al. 2017; for Asia see Reardon et al. 2014).

Third, the available evidence shows that urban consumers have greatly benefitted from the quiet revolution, such as in the potato example where potato prices dropped and potato access deseasonalized with cold storage proliferation in India (das Gupta et al. 2010; Minten et al. 2014), or deseasonalization from longer and wider array of potato supply chains to Beijing.

It also appears that from the cost and quality (and increasingly safety, if private standards are met) viewpoint, the modern transformation also benefitted consumers, eventually with lower prices compared with traditional markets, as both the supply chains modernized and supermarkets shifted to modern procurement systems. For the case of Delhi, see Minten et al. (2010), and an overall review, Minten and Reardon (2008).

The gains were most evidenced in processed and semi-processed foods, which are about 85% of what developing country consumers buy. The economies of scale and scope in these foods have been realized with the transformation of the food system. Of course that food security silver cloud has the dark lining that some processed foods contribute to bad health outcomes such as obesity and diabetes. But the bulk of processed foods and other time saving devices have positive consequences of liberation of women's time for education, labor market participation, and child care (for Nigeria, see Liverpool-Tasie et al. 2016b).

Fourth, with both the quiet and the modern food system revolutions, we note that there has been an increase in volumes and length of the supply chains. One thus moves away from small "niche" local markets to nationally integrated and often more efficient markets. This leads to better price integration but also to a marketing system with relatively smaller marketing costs (as shown in cereal market analysis in Ethiopia, for example; see Minten et al. 2014).

Fifth, both from the high value diversification products being produced, and the large amount of activity post-farm gate occasioned by longer and more developed supply chains, there is a great deal of rural nonfarm employment linked to food supply chains generated by the transformation. There is growing evidence that women and youths are especially benefitted as these are low entry barrier jobs in transport, commerce, food preparation, and small scale processing (for Africa, see Tschirley et al., 2016).

Finally, while there are general estimates of food losses and waste along supply chains (from farm to consumer) in developing countries put at roughly 20%-30% for cereals and pulses and meat and milk and fish, 40% for roots and tubers, and 50% for fruits and vegetables by FAO (summarized in FAO 2011).

However, with the caveat that comparisons of loss and waste measures are rife with challenges due to different measurement methods and inadequate information (Affognon et al.; 2015), most systematic survey based studies of actual actors in the supply chains tend to have much lower figures than the FAO estimates. An example is a unique “stacked survey” based loss/waste measurement approach (Minten et al. 2016b and Reardon et al. 2012) that included details on waste in each segment of the value chains of potatoes and rice in China, India, and Bangladesh. They found only about 5% loss/waste over the whole supply chain for potato (excluding consumer level waste) and about 1% for rice. Kaminski and Christaensen (2014) used national level representative surveys of farm households for farmers estimates of post harvest losses in Malawi, Uganda, and Tanzania, and found a range of 1.4% to 5.9%, much lower than the post-harvest loss estimate of 8% for grains by FAO (2011). They also found that the areas of loss were concentrated among 20% of farms, that were in hotter and humid areas, with less market access (which for us means less developed food systems, in hinterland zones). Lipton (1982) in India had had similar findings, and at that time similarly questioned the then extent FAO estimates of 30-50% loss in grains.

Sheahan and Barrett (2017) contend that it is worthwhile, however, to analyze cost effective measures reduce loss and waste, but argue that pre-harvest actions (such as improved varietals) or chemical sprays and IPM for fields or storage and hermetic technologies (bags and silos) to store more effectively may be warranted, especially in view of some especially problematic loss and food safety problem generators, such as aflatoxins in maize and peanuts (Wu et al. 2011). But Sheahan and Barrett note that we should bear in mind the tradeoffs that farmers consider in terms of health and yields and other attributes. They also note that there has been very little empirical research on the effectiveness and adoption of these techniques. Bellemare et al. (2017) also argue that measures of food waste are conceptually flawed and have led to a large over-estimate of waste in food systems, which is corroborated by the emerging empirical evidence about this.

7. Implications for the agricultural research community and food systems scholars

There are several key implications of our analysis of the pathways of transformation of food systems for agricultural research strategies of the IARCs and NARS.

First, we showed that the food system – the cluster of three sets of supply chains, of inputs, outputs, and upstream and downstream technology R&D - is transforming relatively suddenly, rapidly, and profoundly. It is fair to say that the basics of research strategy and priorities were laid out several decades ago when the food system was deeply different from today, and are due for basic adjustments to match a radically different new reality. 25 years ago, demand was mostly for grains, farm households were little engaged in markets as sellers or buyers, supply chains were just emerging and urban market share was tiny; the only modern market was in the export sector, local markets were still just traditional. Today, about two-thirds of local demand

and thus food systems are in non-staples as consumer demand has diversified way beyond basic grains, into meat and fish (and thus derived demand for feed-grains too), edible oils, dairy, fruits, and vegetables. Within grains, there has been a strong shift toward higher quality cereals. Urban demand is now about half to three-quarters of the market that farmers face, and the needs of those markets become paramount to farmers trying to increase their incomes to exit poverty. Domestic markets are rapidly transitioning and even modernizing; consumers and agribusinesses and food industry firms are proliferating in every region, and are seeking from farmers greater quality, safety, consistency, shelf life, and lower seasonality, and competitive prices. 60% of the consumer price of food, an indicator of food security, is now formed by post-farm-gate actors, the wholesalers, processors, logistics firms, retailers. They, and their upstream counterparts in input supply chains, have now become as important as farmers in determining national food security.

Second, IARCs and NARS have a strong vested interest in researching, understanding, and taking into account the whole food system and its transformation, adapting their strategies, plans, and choice and design of innovations in technologies and products. This also includes understanding the changing government policies, as well as private sector institutions (such as private standards) and procurement system and marketing organization. This is important for several reasons. Opportunities and bottlenecks along all three sets of supply chains determine the potential success of IARC/NARS innovations in the farming segment. Emerging requirements of the changing food system – in terms of product types, quality and safety attributes, shelf life, cost, consistency, seasonality, volumes, and so on - should influence priorities for IARC/NARS innovations. This will help to determine whether innovations in farm technology and products lead to profitable marketed output by farmers, and thus ultimately, whether farmers will have the incentive to adopt new technologies.

Third, we have shown that the great majority of the food system's structure, conduct, and performance are determined by the innovations, investments, and behavior (technology, buying, and selling choices) of the private sector. This includes the emergence to extreme importance to food systems both the vast numbers of micro, small, and medium enterprises (MSMEs) that have emerged in the "quiet revolution," and the powerful agribusiness firms, processors, logistics and wholesale companies, and supermarket chains that have become ubiquitous and important in their emerging dominance of urban food economies and input supply chains. The food system now is a powerful, dynamic locomotive that is growing and moving and changing driven nearly exclusively by the decisions and investments of the private sector – the supermarket chains, the large processors, the big wholesale and logistic firms, the agribusiness firms, as well as the 10's of thousands of MSME's, both farms and off-farm segments, that are making massive aggregate investments upstream and downstream in the system.

IARCs and NARS innovations need a supply chain to implement the innovations they generate. The upstream innovation is the beginning, not the end, of the process. The private sector in the food system is the centerpiece of the supply chain that delivers that upstream innovation. It is essential that IARCs/NARS understand the strategies, behavior, and needs of these two powerful sets of private sector actors, as the latter are essentially and in practical terms in charge of the direction that the entire food system. 25 years ago the private sector in the food system could be just a sidelight and "specialized" issue at the margin of food system thinking and agricultural research strategies: by becoming the dominant, central player in the food system, the private sector cannot be relegated to just a potentially interesting group to consult and observe at the edges. It is now at the center. It is now the group that decides what systems and structures will market and implement the innovations of technologies and products generated by the IARC/NARS. The ability of the latter to understand, adapt to, selectively partner with, the private sector, will in the next decades be an important part of determining the performance of IARC/NARS innovations.

Fourth, the public research community needs to understand and act on the importance of research on the off-farm components of the food system. Research on and productivity of processing, packaging, logistics, and commerce technologies have equal weight in the performance of the food system relative to the farm sector, and investment in research and development (R&D) value chains for these technologies and value chains for the inputs to these segments need a much higher profile in the context of the transformed food system where post farm segments occupy 40-70% of value added. An argument for post-farm-gate research (that it allows reduction of marketing margins in value chains to improve efficiency in the value chain) is usually a win-win for consumers as well as for producers. Moreover, returns on research (RoR) at the farm level clearly depend on concomitant innovations in the supply chain to supply inputs for or market the output of the innovation.

References

Adjognon, S.G., LSO Liverpool-Tasie, T. Reardon. 2017. "Agricultural input credit in Sub-Saharan Africa: Telling myth from facts," Food Policy. 67: 93–105.

Affognon, H., Mutungi, C., Sanginga, P., Borgemeister, C., 2015. "Unpacking postharvest losses in Sub-Saharan Africa: a meta-analysis. World Development, 66, 49-68.

African Development Bank (2016). Feed Africa: Strategy for Agricultural Transformation in Africa 2016-2025. May. Abidjan: African Development Bank.

Amat y Leon, C., D. Curonisy. 1981. Nutrition in Peru. Lima: Universidad del Pacifico.

Austin JE. 1981. Agroindustrial Project Analysis. Baltimore, MD: Johns Hopkins Univ. Press

Barrett, C.B., M.E. Bachke, M.F. Bellemare, H.C. Michelson, S. Narayan, T.F. Walker. 2012. “Smallholder Participation in Contract Farming: Comparative Evidence from Five Countries,” World Development, 40(4): 715-30.

Bellemare, M., M. Çakir, H. Hanawa Peterson, L. Novak, J. Rudi. 2017. “On the measurement of food waste,” American Journal of Agricultural Economics. June.

Belton, B. 2017. “The rapid rise of mechanization services (and outsourcing?) in Myanmar” Powerpoint presented at the workshop on “Outsourced Agricultural Services” at the Institut National de Recherche Agronomique, Toulouse, April 26.

Belton, B., A. Hein, K. Htoo, L. Seng Kham, A. Sandar Phyoe, T. Reardon. 2017. “The emerging quiet revolution in Myanmar’s aquaculture value chain,” Aquaculture, http://dx.doi.org/10.1016/j.aquaculture.2017.06.028

Bennett, MK. 1954. The World’s Food. New York: Harper.

Berdegué, J.A. F. Balsevich, L. Flores, T. Reardon. 2005. “Central American supermarkets' private standards of quality and safety in procurement of fresh fruits and vegetables,” Food Policy, 30(3), June: 254-269.

Binswanger, H.P. 1978. “Induced Technical Change: Evolution of Thought,” in H.P. Binswanger and V.W. Ruttan, Induced Innovation: Technology, Institutions, and Development. Johns Hopkins University Press.

Bloch, R., S. Fox, J. Monroy, A. Ojo. 2015. Urbanisation and Urban Expansion in Nigeria. Urbanisation Research Nigeria (URN) Research Report. London: ICF International.

Braudel, F. 1979. Civilisation matérielle, économie et capitalisme, XVe-XVIIIe siècle. Paris: Armand Colin.

Bricas, N., J. Muchnik. 1985. Technologies aiutochtones et artisanat alimentaire urbain. In Bricas N., G. Courade, J. Coussy, P. Hugon, Muchnik J. (ed.) Nourrir les villes en Afrique sub-saharienne. Paris: L’Harmattan: 293-310.

Byerlee, D. and C. Eicher (ed.). 1997. Africa’s Emerging Maize Revolution. Boulder: Lynne Rienner Publishers.

Das Gupta, S., T. Reardon, B. Minten, S. Singh. 2010. The Transforming Potato Value Chain in India: From a Commercialized-Agriculture Zone (Agra) to Delhi. Report of Value Chains Component of Asian Development Bank RETA (13th) IFPRI Project on Policies For Ensuring Food Security In South And Southeast Asia. October.

Dela Cruz, A., R. Hernandez, L. Digal, T. Reardon, S. Qanti, and B. Minten. 2010. Mango Farmers, Sprayer-Traders, and Modern Market Channel Participation in Pangasinan Province, Philippines: Survey-based Evidence and Implications. Report of MSU to Asian Development Bank under project Strengthening Institutions for Investment Climate and Competitiveness. April.

Dolislager, M.D., D. Tschirley, and T. Reardon. 2015. Consumption patterns in Eastern and Southern Africa. Report to USAID by Michigan State University, Innovation Lab for Food Security Policy, May.

Escobal J, Agreda V, Reardon T. 2000. Institutional change and agroindustrialization on the Peruvian coast: innovations, impacts, and implications. Agric. Econ. 23(3):267–78

FAO. 2011. 2011. Global Food Losses and Food Waste: Extent, causes and prevention. Rome: FAO.

Farina, EMMQ, G.E. Gutman, P.J. Lavarello, R. Nunes, T. Reardon. 2005. "Private and public milk standards in Argentina and Brazil," Food Policy, 30(3), June: 302-315.

Farina, E.M.M.Q., M.K. Marino, and T.M. Guedes. 2000. "Nestlé-Socôco: Private Certification In Quality Management." Case study presented at the Maple Leaf Conference, Chicago, 2000.

Ghezán, G., Mateos, M., Viteri, L. 2002. Impact of supermarkets and fast-food chains on horticultural supply chains in Argentina. Development Policy Review 20 (4), 389-408.

Goodhue RE, Rausser GC. 2003. Value differentiation. J. Agric. Resour. Econ. 28(3):375–95

Gow, HR, Swinnen JFM. 1998. Up- and downstream restructuring, foreign direct investment, and hold-up problems in agricultural transition. Eur. Rev. Agric. Econ. 25(3):331–50.

Haggblade, S. 2011. "Modernizing African Agribusiness: Reflections for the Future." Journal of Agribusiness in Developing and Emerging Economies 1 (1): 10–30.

Haggblade, S., P. Hazell, T. Reardon (eds.). 2007. Transforming the Rural Nonfarm Economy: Opportunities and Threats in the Developing World, Johns Hopkins University Press. October.

Haggblade, S., B. Minten, C. Pray, T. Reardon, D. Zilberman. 2017. "The Herbicide Revolution in Developing Countries: Patterns, Causes and Implications," European Journal of Development Research. 29(3), June: 1-27.

Hayami, Y., and Ruttan, V.W. 1971. Agricultural Development: An International Perspective. Baltimore: Johns Hopkins Univ. Press.

Henson, S. and T. Reardon. 2005. "Private agri-food standards: Implications for food policy and the agri-food system," Food Policy, 30(3), June: 241-253.

Hernandez, R.A., B. Belton, T. Reardon, C. Hu, X. Zhang, A. Ahmed. 2017. "The 'quiet revolution' in the aquaculture value chain in Bangladesh," Aquaculture, http://dx.doi.org/10.1016/j.aquaculture.2017.06.006

Hirschman AO. 1958. The Strategy of Economic Development.

Hollinger, F., and J. Staatz. 2015. Agricultural Growth in West Africa: Market and Policy Drivers. Rome, Italy: Food and Agricultural Organization of the United Nations.

Hu, D., T. Reardon, S. Rozelle, P. Timmer, H. Wang. 2004. "The Emergence of Supermarkets with Chinese Characteristics: Challenges and Opportunities for China's Agricultural Development," Development Policy Review, 22(4), Sept.: 557-86.

Huang, J , Wang, X, H. Qiu. 2012. *Small-scale farmers in China in the face of modernisation and globalisation*, IIED/HIVOS, London/The Hague.

Jia, C., D. Jukes. 2013. "The national food safety control system of China – A systematic review. 32: 236-245.

Kaminski, J. and L. Christaensen. 2014. "Post-harvest loss in Sub-Saharan Africa – what do farmers say?" Global Food Security 3: 149-158.

Kelly, V., T. Reardon, A. A. Fall, B. Diagana, L. McNeilly. 1993. Final Report of IFPRI/ISRA Project (1988-1992) on Consumption and Supply Impacts of Agricultural Price Policies in Senegal, August (Washington: IFPRI).

Kennedy, E. and T. Reardon. 1994. "Shift to Non-traditional Grains in the Diets of East and West Africa: Role of Women's Opportunity Cost of Time in Prepared-Food Consumption," Food Policy, 19 (1), February: 45-56.

Khlangwiset, P. and F. Wu. 2010. "Costs and efficacy of public health interventions to reduce aflatoxin-induced human disease." Food Additives & Contaminants: Part A. 27(7): 998-1014.

Lipton, M. 1982. Post-harvest technology and the reduction of hunger. Institute of development studies Bulletin: 13(3): 4-11.

Lipton, M. with R. Longhurst. 1989. New Seeds for Poor People. Baltimore: Johns Hopkins University Press.

Liverpool-Tasie, LSO, S. Adjognon, O. Kuku-Shittu. 2015. "Productivity effects of sustainable intensification: The case of Urea deep placement for rice production in Niger State, Nigeria," African Journal of Agricultural and Resource Economics Volume 10 (1), 51-63

Liverpool-Tasie, LSO., Omonona, B. Sanou, A., Ogunleye, W., Padilla, S and Reardon, T. (2016). Growth and transformation of chicken and eggs value chains in Nigeria. Food Security Policy Research Paper No. 22. East Lansing, MI: Feed the Future Innovation Lab for Food Security Policy. http://fsg.afre.msu.edu/fsp/nigeria/FSP_Research_Paper_22_Finaldocx.pdf

Liverpool-Tasie, LSO, T. Reardon, SG Adjognon, A. Sanou. 2016b. "The Economics of the Transformation of Household Food Consumption in West Africa", Contributed paper presented at AAEA annual meetings, Boston, August 1.

Liverpool-Tasie, LSO, Reardon, T. and Abagyeh-Igbudu I. J. (2017). Rapid agri-food system transformation in sub-Saharan Africa: Evidence from processed food inventories in Nigeria. Presented paper at the 2017 Annual Meeting, Agricultural and Applied Economics Association, Chicago, IL.

McCann, J. 2001. Maize and Grace: History, Corn, and Africa's New Landscapes, 1500-1999. Comparative Studies in Society and History. 43(2), April: 246-272.

Mellor, J.W. 1976. The New Economics of Growth: A Strategy for India and the Developing World, Ithaca, N.Y.: Cornell University Press.

Michelson, H., S. Boucher, X. Cheng, J. Huang, X. Jia. 2017. "Connecting supermarkets and farms: the role of intermediaries in Walmart China's fresh produce supply chains." Renewable Agriculture and Food Systems. January. 10.1017/S174217051600051X : 1-13.

Milicevic, X., Berdegue, J. A., & Reardon, T. (1998). Impacts on rural farm and nonfarm incomes of contractual links between agroindustrial firms and farms: The case of tomatoes in Chile. In Proceedings of the meetings of the association of farming systems research and extension (AFSRE), November 30–4 December, Pretoria, South Africa.

Minten, B., T. Reardon, K. Chen, in collaboration with S. Das Gupta, Z. Kan, X. Guo, and M. Punjabi. 2010. The Quiet Revolution of "Traditional" Agricultural Value Chains in Asia: Evidence from Staple Food Supply to Four Mega-Cities. Report of Value Chains Component of Asian Development Bank RETA (13) IFPRI Project on Policies For Ensuring Food Security In South And Southeast Asia. December.

Minten, B., KAS Murshid, and T. Reardon. 2013. "Food quality changes and implications: Evidence from the rice value chain of Bangladesh," World Development, 42, February: 100-113.

Minten, B. and T. Reardon. 2008. "Food Prices, Quality, and Quality's Pricing in Supermarkets vs Traditional Markets in Developing Countries," Review of Agricultural Economics. 30(3), Fall: 480-490.

Minten, B., T. Reardon, S. Das Gupta, D. Hu, K.A.S. Murshid. 2016b. "Wastage in Food Value Chains in Developing Countries: Evidence from the Potato Sector in Asia" In A. Schmitz, P. L. Kennedy, T. Schmitz (Eds.) Food Security in a Food Abundant World. Frontiers of Economics and Globalization (Book 16). Emerald Group Publishing: 225-238.

Minten, B., T. Reardon, K.M. Singh, R. Sutradhar. 2014. "The new and changing roles of cold storages in the potato supply chain in Bihar," Economic and Political Weekly, XLIX (52), December 27: 98-108.

Minten, B., T. Reardon, and R. Sutradhar. 2010. "Food Prices and Modern Retail: The case of Delhi," World Development, 38(12): 1775-1787.

Minten, B., Tamiru, S., Stifel, D. (2014), Structural transformation in cereal markets in Ethiopia, Journal of Development Studies, 50(5): 611-629

Minten, B., Tamiru, S., Engida, E., Tadesse, K. (2016), Transforming staple food value chains in Africa: The case of teff in Ethiopia, Journal of Development Studies, 52(5): 627-645

Neven, D., T. Reardon, R. Hernandez, and G. Tembo. 2017. Smallholder farmer participation in modernization of a food system: The dairy value chain in Zambia. Rome: FAO.

Nweke, F. 1996. Cassava: A cash crop in Africa. Ibadan: IITA.

Ohimain, EI. 2014. "Prospects of the Nigerian wheat transformation agenda," International Journal of Engineering Science and Innovative Technology, 3(5): 139-43.

Pingali, P. 2007. "Westernization of Asian diets and the transformation of food systems: implications for research and policy." Food Policy 32(3): 281–298.

Poapongsakorn, N. 2012 Livestock industrialization in Asia: Growth, scaling up, competitiveness and outlook for smallholders. Asian Livestock: Challenges, opportunities, and response. Proceedings of an international policy forum held in Bangkok, Thailand, 16-17 August 2012

Qanti, S.R., T. Reardon, A. Iswariyadi. 2017. “Triangle of linkages among modernizing markets, emergence of sprayer-trader services, and technology intensification by mango farmers in Indonesia.” Bulletin of Indonesian Economic Studies, Accepted author version posted online: 20 Mar 2017; pages 1-32. http://dx.doi.org/10.1080/00074918.2017.1299923

Reardon, T. 2015. “The Hidden Middle: The Quiet Revolution in the Midstream of Agrifood Value Chains in Developing Countries,” Oxford Review of Economic Policy, 31(1), 45-63.

Reardon, T. 1993. "Cereals Demand in the Sahel and Potential Impacts of Regional Cereals Protection," World Development, 21 (1): January: 17-35.

Reardon, T., C.B. Barrett, J.A. Berdegué, J. Swinnen. 2009. “Agrifood Industry Transformation and Farmers in Developing Countries,” World Development. 37(11): 1717-1727.

Reardon, T. and J.A. Berdegué. 2002. The Rapid Rise of Supermarkets in Latin America: Challenges and Opportunities for Development,” Development Policy Review, 20 (4), September: 317-34.

Reardon, T. J.A. Berdegué, F. Echánove, R. Cook, N. Tucker, A. Martínez, R. Medina, M. Aguirre, R. Hernández, F. Balsevich. 2007. Supermarkets and Horticultural Development in Mexico: Synthesis of Findings and Recommendations to USAID and GOM, Report submitted by MSU to USAID/Mexico and USDA/Washington, August.

Reardon, T., KZ Chen, B. Minten, L. Adriano, TA Dao, J. Wang, S. Das Gupta. 2014c. “The Quiet Revolution in Asia’s Rice Value Chains,” Annals of the New York Academy of Sciences, 1331: 106–118.

Reardon, T., K.Z. Chen, B. Minten, and L. Adriano. 2012b. The Quiet Revolution in Staple Food Value Chains in Asia: Enter the Dragon, the Elephant, and the Tiger. Asian Development Bank and IFPRI, December.

Reardon, T., J-M. Codron, L. Busch, J. Bingen, C. Harris. 1999. “Global Change in Agrifood Grades and Standards: Agribusiness Strategic Responses in Developing Countries,” International Food and Agribusiness Management Review, 2 (3/4): 421-435.

Reardon, T., S. Henson, and J. Berdegué. 2007. “‘Proactive Fast-Tracking’ Diffusion of Supermarkets in Developing Countries: Implications for Market Institutions and Trade,” Journal of Economic Geography 7(4): 1-33.

Reardon, T., P. Matlon, and C. Delgado. 1988. "Coping with Household-level Food Insecurity in Drought-Affected Areas of Burkina Faso," World Development, 16 (9): 1065-1074.

Reardon, T. and B. Minten. 2011. The Quiet Revolution in India’s Food Supply Chains. IFPRI Discussion Paper No. 01115. September. Washington, DC: IFPRI.

Reardon, T., B. Minten, K. Chen, S. Das Gupta, T.A. Dao, J. Wang, KAS Murshid. 2014. Tied Output-Credit Markets Have Come Untied: The Fall of Traditional Agrifood Value Chain Finance in Asia. MSU, IFPRI. August. Paper for the Asian Development Bank, Manila

Reardon, T., K. Stamoulis, and P. Pingali. 2007. "Rural nonfarm employment in developing countries in an era of globalization," Agricultural Economics 37 (s1): 173-183.

Reardon, T. and C.P. Timmer. 2014. "Five Inter-Linked Transformations in the Asian Agrifood Economy: Food Security Implications," Global Food Security. 3(2): 108-117.

Reardon, T. and CP Timmer. 2012. "The Economics of the Food System Revolution," Annual Review of Resource Economics," 14: 225-264.

Reardon, T., C.P. Timmer, C.B. Barrett, J. Berdegue. 2003. "The Rise of Supermarkets in Africa, Asia, and Latin America," American Journal of Agricultural Economics, 85(5), Dec.: 1140-1146.

Reardon, T., D. Tschirley, B. Minten, S. Haggblade, S. Liverpool-Tasie, M. Dolislager, J. Snyder, C. Ijumba. 2015. "Transformation of African Agrifood Systems in the New Era of Rapid Urbanization and the Emergence of a Middle Class," chapter 4 in Badiane, O. and T. Makombe (editors). *Beyond a Middle Income Africa: Transforming African Economies for Sustained Growth with Rising Employment and Incomes*. ReSAKSS Annual Trends and Outlook Report 2014. International Food Policy Research Institute.

Reardon, T., D. Tschirley, M. Dolislager, J. Snyder, C. Hu, and S. White. 2014b. Urbanization, Diet Change, and Transformation of Food Supply Chains in Asia, Report for USAID Michigan State University Project of the Global Center for Food System Innovation and the Food Security Policy Innovation Lab, May.

Reardon, T., D. Zilberman. 2017. Climate smart food supply chains in developing countries in an era of rapid dual change in agrifood systems and the climate. Chapter in L. Lipper, N. McCarthy, D. Zilberman, S. Asfaw and G. Branca, editors. Climate Smart Agriculture - Building Resilience to Climate Change. New York: Springer.

Rello, F. 1996. Rural nonfarm employment in Zamora, Mexico. Report to FAO Rome. Mexico City: UNAM.

Schneider, M. (2011), Feeding China's Pigs: Implications for the Environment, China's Smallholder Farmers and Food Security, Minneapolis, Institute for Agriculture and Trade Policy.

Senauer B, Sahn D, Alderman H. 1986. The effect of the value of time on food consumption patterns in developing countries: evidence from Sri Lanka. Am. J. Agric. Econ. 68(4):920–27

Sheahan, M. and C.B. Barrett. 2017. "Review: Food loss and waste in Sub-Saharan Africa," Food Policy 70: 1-12.

Swinnen JFM, ed. 2007. Global Supply Chains, Standards and the Poor. Wallingford, UK: CABI.

Swinton, S., B. van Deynze. 2017. "Hoes to Herbicides: Economics of Evolving Weed Management in the United States," The European Journal of Development Research, 29(3), July: 560-574.

Timmer, C. P. (2015), ‘The Dynamics of Agricultural Development and Food Security in Southeast Asia: Historical Continuity and Rapid Change’, in I. Coxhead (ed.), Routledge Handbook of Southeast Asian Economics, London and New York, Routledge, 89–113.

Timmer, C.P, S. Block and D. Dawe. 2010. “Long-run Dynamics of Rice Consumption, 1960-2050, chapter 1.6 in S. Pandey, D. Byerlee, D. Dawe, A. Dobermann, S. Mohanty, S. Rozelle, and W. Hardy, editors. Rice in the Global Economy: Strategic research and policy issues for food security. Los Banos (Philippines): International Rice Research Institute:139-174.

Tschirley, D., M. Kondo and J. Snyder (2016). “Chapter 3: Downstream Report” in Allen et al., Agrifood Youth Employment and Engagement Study”. The MasterCard Foundation and Michigan State University.

Tschirley, D., T. Reardon, M. Dolislager, and J. Snyder. 2015. “The Rise of a Middle Class in Urban and Rural East and Southern Africa: Implications for Food System Transformation,” Journal of International Development, 27(5), July: 628-646.

United Nations. 2011. World urbanization prospects: The 2011 revision - Highlights. United Nations, Economic and Social Affairs, New York.

United Nations. 2014. World Urbanization Prospects, 2014. New York: United Nations.

Weatherspoon, D.D and T. Reardon. 2003. “The Rise of Supermarkets in Africa: implications for agrifood systems and the rural poor,” Development Policy Review, May, 21(3): 333-355.

Williamson OE. 1981. The economics of organization: the transaction cost approach. Am. J. Sociol. 87(3):548–77

Wu, F., Narrod, C., Tiongco, M., Liu, Y., 2011. The Health Economics of Aflatoxin: Global Burden of Disease. International Food Policy Research Institute Aflacontrol Working paper 4. Washington, DC.

Zhang, X. and Hu, D., 2014. Overcoming successive bottlenecks: The evolution of a potato cluster in China. World Development, 63 (2014), 102-112.

Zhang, X., J. Yang, T. Reardon. 2017. “Mechanization outsourcing clusters and division of labor in Chinese agriculture. China Economic Review. 43: 84–195

Zheng, Y. 2013. “Corn overtakes rice as leading foodstuff,” China Daily; April 11. http://www.chinadaily.com.cn/bizchina/2013-04/11/content_16393116.htm

Zilberman, D., L. Lu, T. Reardon. 2017. “Innovation-induced food supply chain design,” Food Policy. In press. http://dx.doi.org/10.1016/j.foodpol.2017.03.010

Table 1: Domestic food supply quantities (approximation of consumption by disappearance) & composition in millions of tons & population

	1970	1990	2013
Africa food supply quantity (ton/capita/yr)	0.46	0.49	0.59
population (in millions)	339m	581m	995m
Africa total domestic food supply	156	285	587
Imports into Africa, tons (share of total domestic food supply)	11 (7%)	42 (15%)	123 (21%)
Exports from Africa, tons (share of total domestic supply)	17 (11%)	15 (5%)	39 (7%)
Staples: cereals (% total)	44 (28%)	84 (29%)	150 (26%)
Staples: roots & tubers (not potato) (% total)	34 (21%)	53 (19%)	116 (20%)
Non-staples (% in total)	79 (50%)	148 (52%)	320 (55%)
Asia food supply quantity (ton/capita/yr)	0.37	0.43	0.65
population	2.07b	3.13b	4.26b
Asia total domestic food supply	758	1,357	2,786
Imports into Asia, tons (share of total domestic food supply)	70 (9%)	176 (13%)	507 (18%)
Exports from Asia, tons (share of total domestic supply)	30 (4%)	90 (7%)	284 (10%)
Staples: cereals (% total)	300 (40%)	507 (37%)	663 (24%)
Staples: roots & tubers (not potato) (% total)	111 (15%)	87 (6%)	70 (3%)
Non-staples (% in total)	348 (46%)	762 (56%)	2,053 (74%)
LAC food supply quantity (ton/capita/yr)	1.57	1.67	2.02
population	284m	441m	611m
LAC total domestic food supply	447	737	1,232
Imports into LAC, tons (share of domestic supply net of exports)	15 (3%)	42 (6%)	107 (9%)
Exports from LAC, tons (share of domestic supply)	48 (11%)	84 (11%)	271 (22%)
Staples: cereals (% total)	99 (22%)	162 (22%)	230 (19%)
Staples: roots & tubers (not potato) (% total)	38 (8%)	38 (5%)	65 (5%)

Non-staples (% in total)	310 (69%)	536 (73%)	937 (76%)