Markets, Policies and Technology: pathways for zero deforestation agriculture

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Executive Summary

Improving sustainable agricultural production in non-forest lands is a global challenge with consequences to both food security, conservation of biodiversity and climate change. At a global level, since 2000, increases in agricultural output have relied more heavily on productivity gains than on the expansion of crops into new lands. This trend shows that the ambition of stopping deforestation is more than a theoretical possibility. Two conclusions can be drawn from this evidence: (a) zero-conversion agriculture does not compromise increases in agricultural output and (b) more food can be produced by improving land management. Yet, the Global Forest Watch continues to show that significant tree cover loss worldwide due to agriculture, putting at stake valuable natural resources and the services they provide.

Country-level analysis reveals different patterns for agricultural expansion. In the United States, for instance, the increase in agricultural production is happening through productivity gains and farmland reduction since the 1960s. In Indonesia and Brazil, on the other hand, yield gains are concomitant with area expansion, although the expansion in farmland is slowing down in the most recent years.

It is in this context that better natural resource management, particularly land and water, is key for the future of food industry, especially in developing countries where production processes are lagging behind in terms of their adoption of resource-saving technology that is available in more developed countries. Misaligned price signals, distortionary policies and market frictions prevent farmers from operating their lands efficiently. These barriers reduce the pace at which the agricultural sector evolves, especially in developing countries, increasing the pressures for conversion.

This paper provides a framework to assess how markets, policies, and technology can affect yields gains and thus promote zero-conversion agriculture. In this framework, efficiency gains can be generated by improving agricultural practices and technology in established farmers or by replacing unproductive farmers by efficient ones.

Markets have an important role in driving the economy towards zero-conversion agriculture. Financial markets, through credit and risk management tools, allow farmers to invest in efficient and sustainable practices. While credit can fund upfront costs of yield enhancing investments, there are many cases in which sustainable practices have higher return but also higher risks. Land markets, through sales or rental arrangements, improve the match between farmers and farms. And the markets for agricultural products can contribute by providing signals to the supply chain about how agricultural goods should be produced. In all of these cases, along with the potential of markets to improve land use efficiency, there are frictions and challenges preventing markets to fulfill its potential. The end-result is that, due to these frictions, the true costs of food

production is not fully captured by price. Therefore, policy is needed to correct market failures.

Policies complement markets by providing price signals for efficient provision of environmental services, preserving areas of environmental interest and fostering activities for the best use of cleared areas. Effective conservation policies are essential to drive production expansion away from high priority areas for conservation. Infrastructure projects, especially those on logistics, can induce the necessary investments for improving productivity in already cleared areas. However, as better infrastructure changes the market access of specific locations, they also might drive deforestation up. Thus, efficient land use requires a coordination between infrastructure investments and conservation policies to mitigate possible damages to the environment. Public finance, as one of the most common tools that influence land use policy around the world, can be an important ally for promoting zero-conversion agriculture. In particular, there are examples of better alignment between the allocation of public finance and the provision of public goods, as well as innovative risk management public interventions.

Finally, efficient arrangements for technology dissemination are still a challenge. There is evidence of relevant frictions in the diffusion of information on practices across farmers. The literature points to the importance of a few key elements, such as the need of providing incentives to disseminators, the importance of communication and social learning. However, there is no consensus on the best way of designing the marketing of best practices.

In sum, the good news is that the agenda of zero deforestation agriculture seems a feasible ambition given the global evolution of agricultural production, especially with the most recent trends. The challenge is how to align markets, policies and technology diffusion so we can increase the pace in which this process take place, especially in the developing world. Although some elements are clearly important, the adequate set of initiatives seems to be context-specific and its design is still an open issue.

I. A framework for improving land use efficiency

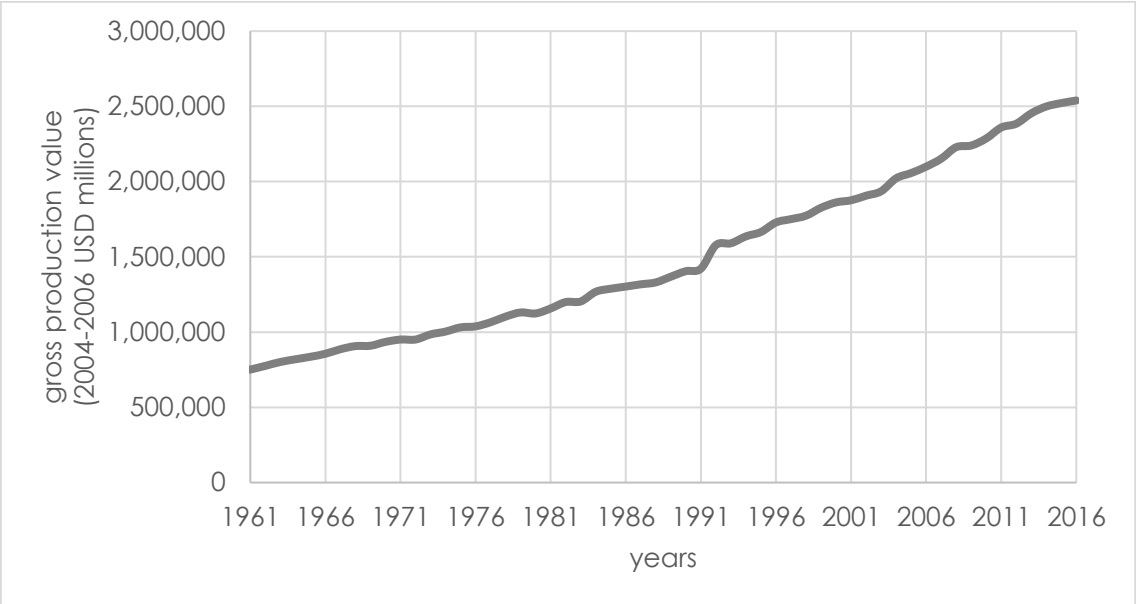
There are two key sources of food production growth. On the one hand, production can increase with the expansion of farmland. Even in the absence of productivity gains, agricultural output can increase as a direct consequence of a larger cultivated area. This process is usually associated with the conversion of native vegetation, with collateral damage to climate and biodiversity. On the other hand, yield gains allow production to increase without area expansion. This process is limited by the technological possibilities as well as the ability of farmers to implement best practices.

Zero deforestation agriculture in the context of a growing population and food security requires the expansion of food production in non-forest lands, through yield gains rather than farmland expansion. This section illustrates the evolution of agricultural growth, showing that a transition from extensive and area-based agriculture towards intensified production is more than a theoretical possibility. Then, it presents a framework for improving land use efficiency, especially in developing countries.

I.1 Alternative ways of expanding agriculture

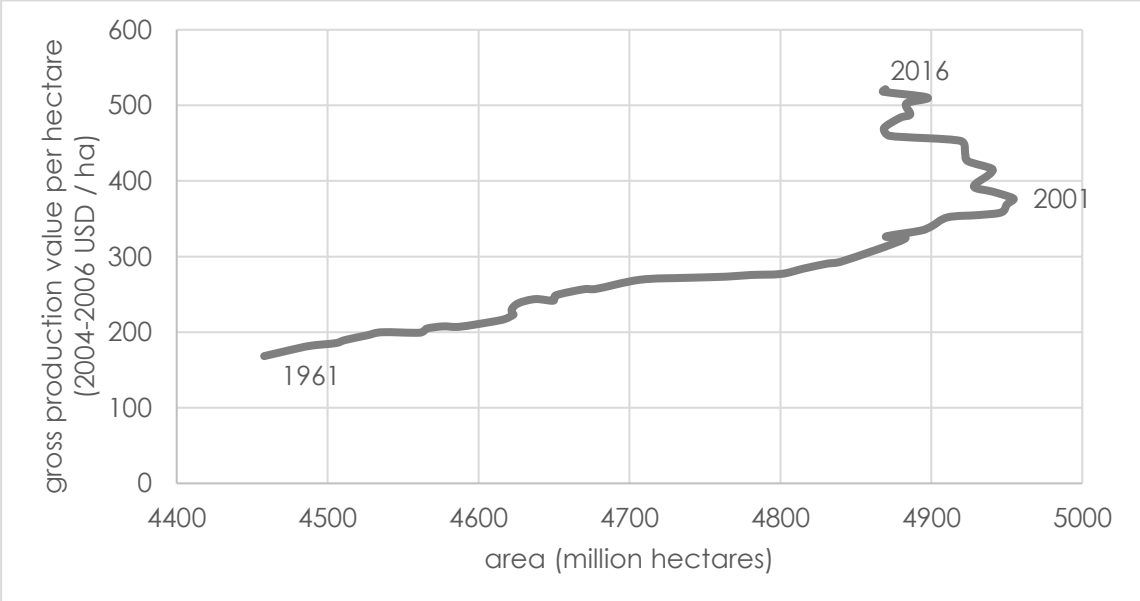
In aggregate terms, the world has been able to expand agricultural production continuously at higher rates than the population growth. In the 1961-2016 period, the world population increased from 3 billion to 7.3 billion people, while the value of agriculture production increased from USD 750 billion to USD 3 trillion (see Figure 1). However, there is growing interest, especially in modern societies, in how we produce our food results in externalities on the environment and which impact human health.

Figure 1 - Evolution of Global Agricultural Production (1961-2016)



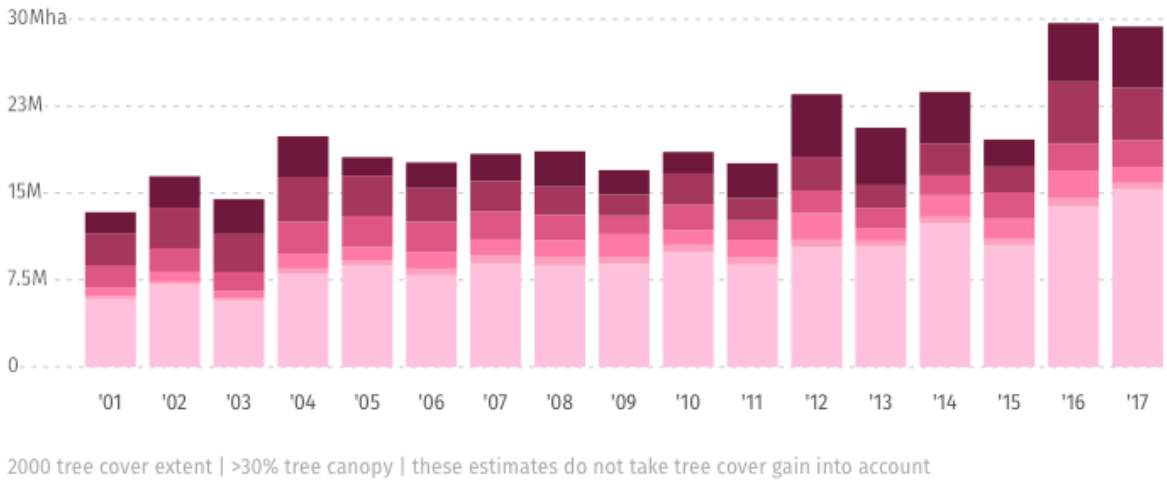
Source: FAOSTAT

Figure 2 - Productivity and Area Expansion in World Agriculture (1961-2016)



Source: FAOSTAT

Figure 3 - Evolution of Global Tree Cover Loss

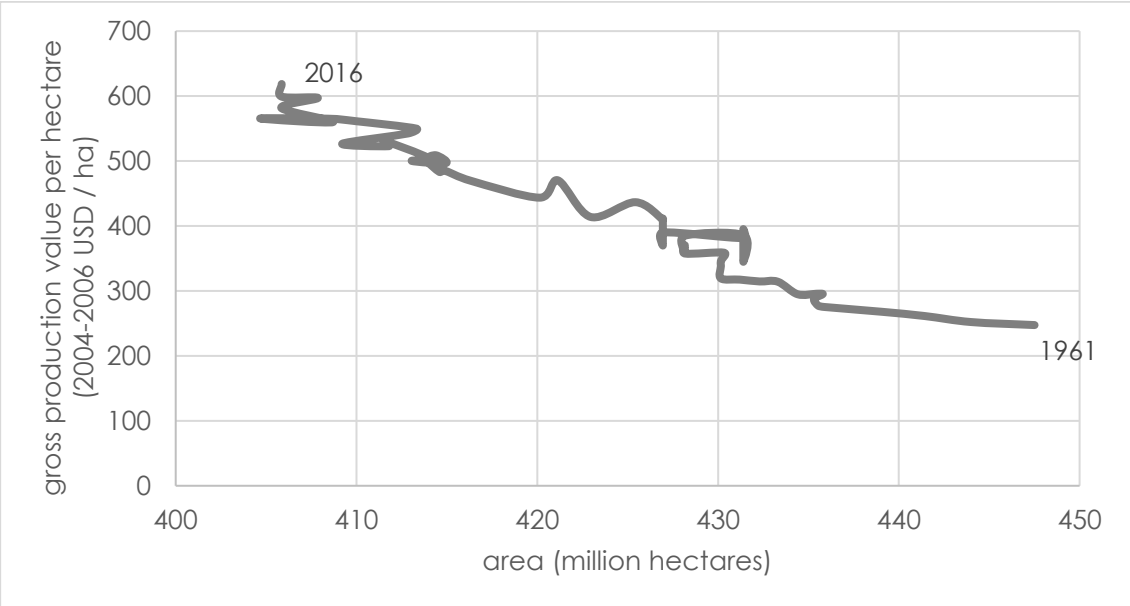


Source: Global Forest Watch, World Resources Institute

The steady evolution of agriculture production in this 55-year period covers up a dramatic change in the growth pattern. As shown in Figure 2, until 2000, the global production increase was a combination of yield gains and area expansion. After 2000, however, the productivity gains were such that the production growth occurred with a reduction in the total agricultural land. The intensification of production, which reduces the pressure for deforestation, prevails in the aggregate figures in the 2000s. Paradoxically, global tree cover losses increased during the 2000s according to the Global Forest Watch (Figure 3).

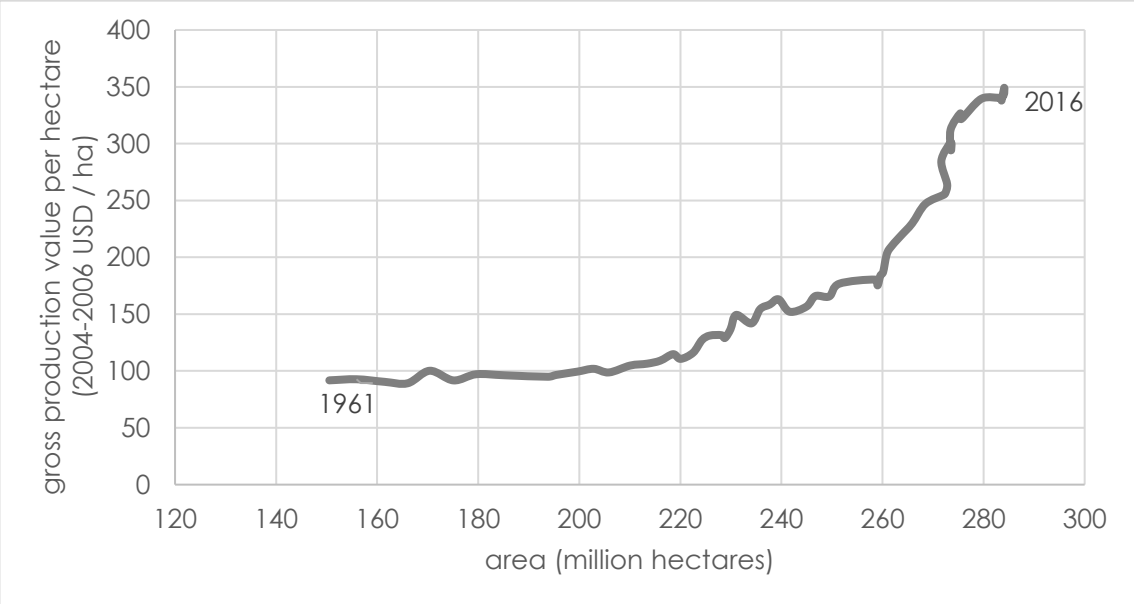
While the aggregate figures suggest that the evolution of agriculture is associated a trend of less land required per unit of production, there is still a quite heterogeneous scenario at country levels. The analysis of specific countries reveals different expansion patterns.

Figure 4 - Productivity and Area Expansion in the United States (1961-2016)



Source: FAOSTAT

Figure 5 - Productivity and Area Expansion in Brazil (1961-2016)

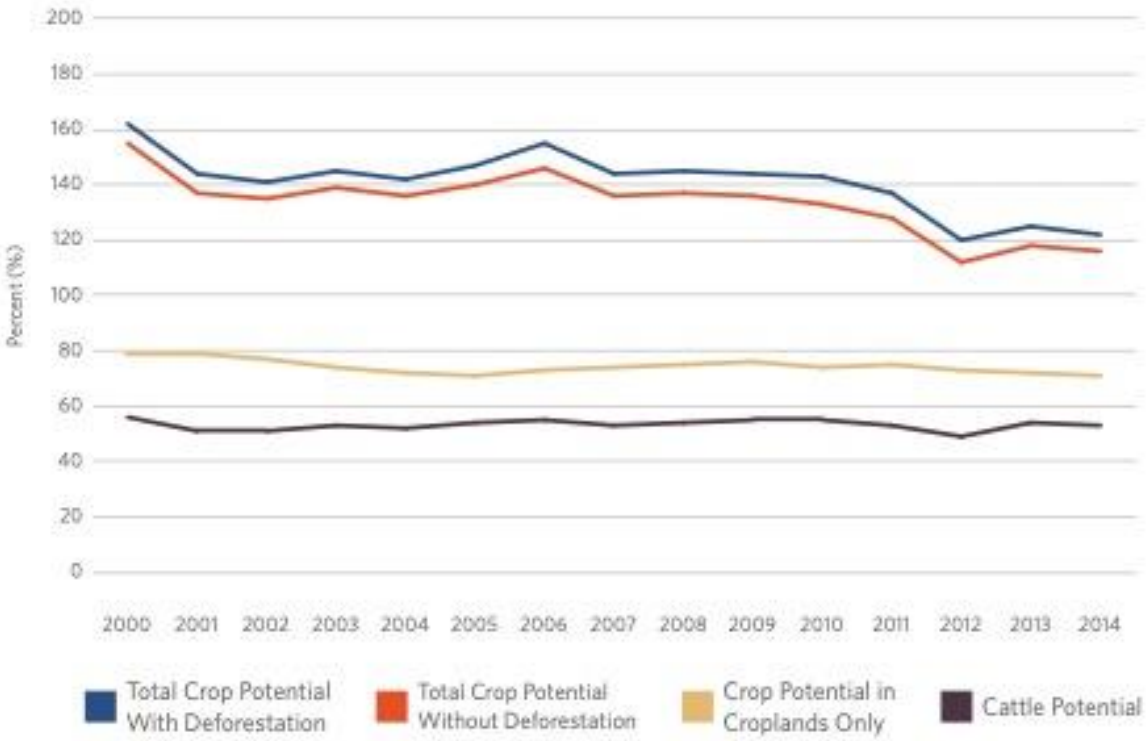


Source: FAOSTAT

Figure 6 - Productivity and Area Expansion in Indonesia (1961-2016)

Source: FAOSTAT

Figure 7 – The Potential for Productivity Gains from Different Land Use Strategies in Brazil



Source: Antonaccio et al (2018).

Figure 4 shows that the evolution of the American agriculture is driven by yield gains and area reductions. Other developed countries depict a similar pattern according to FAO data. On the other hand, in developing countries such as Brazil and Indonesia, there is an increase in farmland along with productivity gains (Figures 5 and 6).

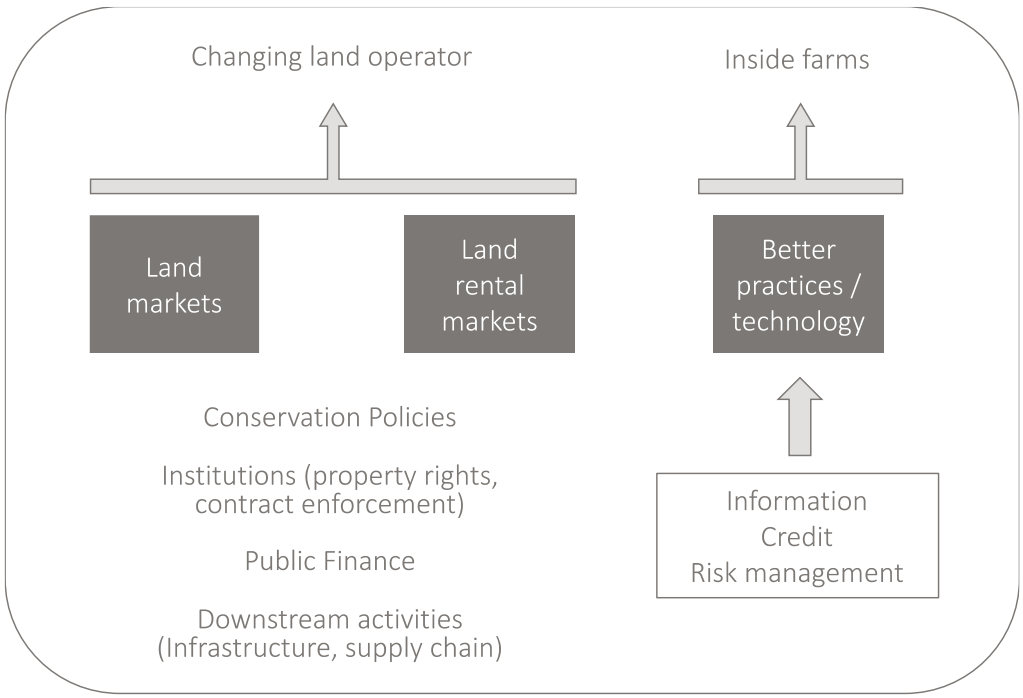
For the case of Brazil, Figure 7 shows that the process of increasing yields is far from its full potential. The graphs, based on econometric models, estimate the unrealized agricultural potential, based on municipal-level data, under four scenarios. In the first scenario, farmers are allowed to increase production through area expansion (deforestation), conversion of pastureland into cropland, or productivity gains. In 2014, the estimated potential for increase crop production is 120% - the decrease in the estimated potential shows that Brazil is realizing this potential over time. In the second scenario, farmers are not allowed to increase farmland and thus are restricted to increase crop production through the conversion of pastureland into cropland and also through yield gains. Interesting enough, the estimated potential is quite similar to the figure obtained with deforestation – most of the gains to be realized are associated with cleared areas. In addition, there is scope for increasing yields in croplands about 70% (third scenario) and in cattle ranching about 60% (forth scenario). Indeed, the convex shape of Figure 5 suggests Brazil is reaching a turning point in which the upcoming expected gains are more likely to be associated with yield gains rather than area expansion.

I.2 A framework for improving land use in agriculture

Conceptually, increasing agricultural productivity has two distinct dimensions – (i) the technology innovation, which expands the frontiers of production possibilities and (ii) the dissemination of best practices, which assigns each hectare of land to its most efficient use. The focus here is on the technology dissemination dimension.

Allocating land to its best use is a multidimensional challenge, especially when considering the political and institutional arrangements in place. Figure 8 presents a possible framework for delivering efficient land use, in which markets, policies and technology dissemination play key roles. The relative importance of each of these levers depends on the specific context under consideration. It is a stylized representation of possible issues affecting productivity gains at different levels.

Figure 8 – Framework for delivering efficient land use



Inside farms

For a given farmer, the ability of improving practices or adopt the best technology is conditioned by the available information and the means of implementing the required changes in production. Human capital and technical assistance are essential. In many instances, better practices require upfront investments and thus, credit might be an important barrier. For example, efficient pastureland management requires investments in fences. Sometimes, improving production is associated with substantial changes in the risk profile of the activity. For example, the adoption of no till systems, which reduces costs, avoids soil erosion and decreases GHG emissions, increases the exposure of crops to plagues. Thus, at the farmer level, technology adoption is dependent not only upon the required information, but also on financial instruments for capital expenditures and risk management.

Changing land operator

But the improvements in land use might require a change in the land operator. Following market dynamics as in any other sector, efficiency gains might be associated with the substitution of inefficient farmers by most efficient operators. In these cases, well-functioning land markets have a key role for promoting better resource allocation. Unfortunately, land markets face many frictions in the developing world. For example, there are countries where landholding is motivated not only by its agricultural potential by also as a hedge against macroeconomic instability, source of political power or tax

shelter, land rental markets can support additional efficiency gains since it allows a decoupling between landownership and land cultivation.

Institutions, Policies and Market Signals

The issues presented above describe the mechanics of efficiency gains in land use, related to improvements in the practices of a given farmer or changes in the land operator. The pace at which change occurs depends upon incentives and signals provided by the economic environment where the decisions are made. Conservation policies typically impose constraints on the area expansion and thus, promote intensification in production. Public finance, in the form of subsidized credit, taxes or fiscal transfers, is also another lever used by governments to promote specific agricultural practices. The quality of institutions, through well defined property rights and contract enforcement, created a favorable environment for investment and markets. Finally, farmers' choices are influenced by the availability of infrastructure, which affects the rate of return of agriculture, and other downstream requirements such as supply chain commitments.

II. Markets

II.1 Financial markets

The agricultural sector is naturally linked to financial markets. Credit is particularly important since planting (costs) occur well before harvesting (revenues). Risk management is relevant to help farmers deal with various sources of uncertainty – climate conditions, plagues and price variability. In the absence of proper financial services, farmers may have to forego valuable investments, deteriorating the allocation of resources. These issues are amplified in the context of intensified production, which requires higher investments and better risk management.

In developing countries, financial markets are usually absent or fragmented in the sense that different types of borrowers are sorted across loan types or lending organizations according to characteristics that are not associated with the production potential. For example, farmers might not have credit access due to lack of collateral (Conning and Udry 2005). Indeed, financial access is still a relevant issue in many countries (Karlan and Morduch 2009).

Physical access to financial services is still relevant, given the fixed costs associated with the traditional bank branches. In a careful analysis of a branch expansion program implemented in India, Burgess and Pande (2005) show that branch expansion into rural unbanked locations reduced rural poverty, increasing deposit mobilization and credit disbursement. New institutional arrangements and technology are expanding access to financial services and can complement the services provided by commercial banks and

other players. It is worth mentioning the experience of banking correspondents in Brazil (Assunção 2013) and the M-PESA in Kenya (Suri and Jack 2011). In these two examples, financial providers rely on pre-existing infrastructure (non-financial business in the case of banking correspondents and cell-phone network in the case of M-PESA) as a way of serving customers that could not be reached by the traditional distribution channels. The experience with Self-Help Groups is another example from India (Goto 2013).

The challenges of providing credit in rural areas are well described in the literature and mostly determined by asymmetric information (moral hazard, adverse selection or opportunistic default) and limited enforcement. Well defined property rights, legal enforcement of financial contracts and mechanisms for information diffusion are areas in which the literature suggest as critical for the design of credit markets (Conning and Udry 2005). Risk management activities are also challenging in rural areas not only due to asymmetric information but also to problems associated with costly verification states.

In order to test the relative importance of credit and insurance mechanisms as barriers to investment and production intensification, Karlan et al (2014) implemented large scale experiment with farmers in Ghana. Farmers were randomly assigned to (i) receive cash grants; (ii) opportunity of purchasing rainfall index insurance; (iii) a combination of the two. They not only found a strong demand for insurance, but also documented that insurance leads to larger agricultural investment and riskier production choices. In that particular sample, the binding constraint was uninsured risk rather than credit.

Thus, the ambition of promoting yield gains and enabling conditions for zero deforestation agriculture should consider the provision of financial services, especially in developing countries. New institutional arrangements and technology can increase financial access, while more efficient provision of credit and insurance can promote production intensification.

II.2 Land markets

Well-functioning land sales and rental markets are also essential for creating incentives for investments and improving the allocation of land. Yet, regulatory restrictions on land rental and sales and lack of tenure security are in play in many parts of the developing world (Deininger and Feder 2001).

Land markets, in the absence of frictions, have the potential to curate efficient matches between farms and farmers. However, especially in developing countries, there are many relevant frictions. First, land is an asset with special features that go beyond its agricultural potential. In countries with long history of macroeconomic instability, land ownership provides a hedge against aggregate shocks. In some cases, landholders face favorable tax conditions. Or it can be a source of political power. Assunção (2008) shows evidence on the importance of non-agriculture motives for landholdings in Brazil and

examines its consequences to the efficiency of land allocation. In particular, in the absence of land rental markets, non-agriculture motives for landholding are shown to drive land markets to an inefficient land allocation, reducing the aggregate output.

Second, as pointed out by Besley (1995) in a seminal paper on property rights in Ghana, land tenure systems with constraints on land rights reduces incentives for investments. Threats to land rights are still relevant especially in the developing world. Alston and Mueller (2010) point out how insecure property rights in Brazil can have a significant impact, resulting in land conflicts and extensive expansion of the agricultural frontier, through the action of squatters. Poorly defined property rights create disputes over territories and, therefore, conflicts with victims, especially among vulnerable populations such as indigenous peoples and traditional groups (Alston and Mueller, 2010).

Third, there are explicit constraints on possible contractual arrangements, especially regarding rental markets which are important to promote efficiency in the context of non-agricultural motives for landholding as described in Assunção (2008). For instance, the Brazilian legislation imposes binding and non-renounceable clauses in rental contracts as a form of protecting the renters, such as ceilings on rents, forms of payment, limits on the duration of the contract, preemptive right to renters to renew the contract or buy the land (Assunção and Chiavari 2014).

In summary, well-functioning land markets can drive efficiency promoting better matches between farmers and farms. However, the legal system and the institutional framework prevent this process to happen, especially in developing countries. The combination of land markets and conservation policies can promote relevant efficient gains.

II.3 Product markets

Another source of signals and incentives for implementing zero deforestation agriculture can come from the agricultural product markets. Standards defined by consumers or downstream companies may shape the decision of farmers seeking market access or price premium. Since early 2000s, relevant companies in the food supply chain have suffered increasing pressures to better manage their sourcing practices. By 2017, at least 477 companies exposed to deforestation risks in their supply chain have made zero deforestation commitments (Lambin et al. 2018, Garrett et al. 2019).

The effectiveness of such efforts depends upon a series of factors, from the technology to track the sourcing flows to the industrial organization of the sectors, which can affect the existence of leakages. Lambin et al. (2018) points out the importance of leakages, lack of transparency and traceability, selective adoption and smallholder marginalization as barriers to the impact of supply chain initiatives on deforestation.

Garrett et al (2019) examine 52 zero-deforestation commitments. They find that, although there is a convergence on the criteria used by the companies, they still cover a small share of the global market for commodities with potential risk of deforestation. In addition, the only implementation at a landscape scale they observe in the sample comprises the Amazon biome – other initiatives are predominantly certification programs.

Brazil's Soy Moratorium is examined in more detail by Gibbs et al. (2015), which was the first zero-deforestation agreement in tropical areas. Major soybeans traders agree not to buy soy grown in areas deforested after July 2006 in the Brazilian Amazon. They show that two years before the agreement, about 30% of soy expansion was based on deforestation rather than the conversion of pastureland. After the Soy Moratorium, about only 1% of the new soybean areas were associated with deforestation. This change in the profile of soy expansion might be attributed to the Soy Moratorium, although law enforcement and monitoring was improving drastically in the same period. More recently, the Cerrado Manifesto comprises more than 60 meat and soybean purchasing companies in a commitment to combating deforestation in Cerrado.

Thus, although product markets can potentially provide incentives and price signals to change the pattern of agriculture expansion, there are still many challenges associated with this pathway. But the current initiatives might foster more aggressive strategies in the future when technology can provide better transparency and traceability with increased awareness of final consumers.

III. Policies

III.1 Conservation policies

In order to preserve areas with environmental interest, countries use conservation policies as a way of constraining and regulating economic activities. Parks, protected areas and forest laws are common examples. The contributions of conservation policies for zero deforestation agriculture are twofold. On the one hand, they are important tools for protecting forests and biodiversity, imposing constraints on land conversions. On the other hand, they also promote production intensification when imposing limits to area expansions.

The effectiveness of conservation policies, however, depends on government capacity for monitoring and enforcement of penalties to the violators. In developing countries, poor governance and political reasons challenge the efficacy of those policies. Burgess et al. (2012), analyzing the Indonesian experience with logging and the political economy of permits, show how economic incentives of local bureaucrats and politicians matter for deforestation. They show evidence that the local governments competing among

themselves in a uncoordinated way were increasing inefficiently the number deforestation licenses as a way of attracting investments.

A possible way of bypassing the difficulties associated with poor governance and lack of coordination among local authorities is the use of technology in centralized systems. The Brazilian experience with the satellite-based monitoring system is a useful example in that direction.

By 2004, almost 62 million hectares of forest had been cleared in the Brazilian Amazon. In that year, deforestation rates reached a peak of 2.7 million hectares. As a response to the escalating deforestation rates and increasing international pressure, the Brazilian government launched a new approach for combating Amazon deforestation. An integrated initiative involving thirteen ministries end up proposing an operational project for the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm). The context in which deforestation happens in the Brazilian Amazon is quite challenging not only because its immense extension and operational difficulties for physical access, but also due to poorly defined property rights in many areas.

PPCDAm strengthened monitoring and enforcement in both institutional and technical dimensions. On the institutional side, a presidential decree provided the directives for administrative investigation and punishment of environmental infractions in more detail, increasing the speed of the processes and regulating penalties such as fines, embargoes, seizure of production goods, tools and materials. These measures improve the legal framework and provided greater transparency to the system. But the major leap forward was on the technical dimension, in which high-frequency remote sensing-based monitoring of forest clearings became the backbone of deforestation policies through the System for Real-Time Detection of Deforestation (DETER) developed by Brazil's National Institute for Space Research (Inpe). DETER uses satellite imagery to detect deforestation hotspots and send alerts to the environmental authority for action. This system was the main driver behind the deforestation slowdown observed in the Amazon (Hargrave and Kis-Katos 2013, Assunção et al 2015).

The satellite-based monitoring system overcomes many difficulties associated with local governance its impact on conservation efforts. The identification of the illegal activity is centralized and transparent, improving accountability of governments and allowing civil society to better monitor the performance of law enforcement. The Brazilian experience illustrates how technology can provide better targeting in conservation efforts, even in areas vulnerable to local political interference.

III.2 Infrastructure

Infrastructure projects interact non-trivially with the goal of pursuing zero-deforestation agriculture. On the one hand, better logistics is key for fostering investments and higher yields in already cleared areas. On the other hand, since the seminal work of Pfaff (1999), who analyze deforestation drivers in the Brazilian Amazon, there is a large literature identifying roads as a major deforestation driver.

Especially in developing countries, which are short of infrastructure, the increase of transport networks is inevitable, due to its importance for economic development and growth. For instance, using detailed data on US railroads and waterways, Donaldson and Hornbeck (2016) show that the expansion of railroads in the 1870-1890 period had a dramatic impact on county market access and, as a consequence, on agricultural land values. In the same direction, Donaldson (2018) documents large impacts of railroads expansion in India during the colonial time. Infrastructure investments in developing countries, therefore, might be not only inevitable but desirable.

The relevant question on the relationship between infrastructure and deforestation, thus, is how to build the necessary infrastructure to promote growth and yield gains and, at the same time, mitigate the possible collateral impacts on deforestation. This is an area in which safeguards and technologies such as the satellite-based monitoring systems, in particular, can play a key role. At a broader level, efficient land use and the promotion of zero-deforestation agriculture would require coordinated efforts across conservation policies and infrastructure project development.

III.3 Public finance

Public finance is an important tool for implementing zero deforestation agriculture. As mentioned above, yield gains might not only require upfront investments but also require better risk management. In addition, the use of public finance to address rural issues is widespread around major agricultural countries. Thus, the public resources currently channeled through the many forms of public finance could be better aligned with the zero deforestation agriculture agenda.

Governments have intervened in rural financial markets through concessional loans and regulation rules since the very early times – the Hammurabi's codes set in stone in ancient Mesopotamia, one of the oldest deciphered writings, regulated the operation of credit for farmers, limiting interest rates to 33.3% and creating provisions for the occurrence of droughts and other natural disasters (Conning and Udry, 2005). In Brazil, for instance, the subsidized credit program, which encompasses a series of funding sources and credit lines for agriculture, accounts for approximately 40% of the agricultural production according to the Ministry of Agriculture.

The scope for government intervention is broad (Conning and Udry 2005). The government can act to promote financial trade among private players, providing impartial and accessible legal mechanism for contract enforcement, prudential regulation and supervision of deposit-taking financial intermediaries to mobilize resources and encourage healthy competition among banks. It is also common to direct credit intervention, through direct loans or government guarantees, even in advanced economies, with the goal of crowding in private resources or promoting specific tasks or projects. Interventions can also be heavy handed in the form of capping interest rates or restricting the participation of specific type of intermediaries. Many of these interventions end up promoting financial repression through their impacts on the cost of capital or perceived risks in financial operations. The challenge is how to best calibrate public intervention in order to promote efficient land use.

The experience of the United States and European Union brings some key elements to the design of effective public finance for supporting zero-deforestation agriculture. On the one hand, The Common Agricultural Policy (CAP), European Union's main rural policy, focuses on the environment's protection and rural development, offering direct payments to rural producers that are conditional on the conservation of forests and biodiversity, and the maintenance of good soil conditions. There are also Green Payments, which possess stricter requirements and include maintaining permanent pastures, creating areas of ecological interest, and diversifying crops. In the European case, there is a tight relationship between subsidies and public good provision. In the United States, on the other hand, there is a strong emphasis on insurance mechanism and public-private partnerships.

In a country like Brazil, where public finance is one of the major funding sources for farmers and the basic features of the subsidized credit program were determined in the 1960s, the features above point to promising directions – higher participation of risk management instruments and better alignment with public goods. The current framework was determined when the country's challenges, the Brazilian agriculture and farmers needs were quite different. As shown in Karlan et al (2014), insurance is a key barrier for production intensification. In addition, the public finance should support the agriculture that is more aligned with sustainable practices, through low carbon agriculture and focusing on conservation policies, in particular, the Forest Code.

IV. Technology dissemination

Technology dissemination is a world challenge, especially in agriculture, in which the number of decisionmakers is so large. Marketing best practices in agriculture not only depends on the ability of dealing with large number of farmers, scattered over extensive territories, but also on how suitable those practices are to local conditions.

The dissemination of a no-till agriculture practice best known as the Direct Planting System (DPS) in Brazil is quite emblematic about possible barriers preventing adoption. The DPS was developed in Southern Brazil at the beginning of the 1970s as a way of avoiding soil erosion. In the DPS, there is no tillage and the crop residuals are left on the surface – weed control is made through herbicides. The DPS is a special no-till method in which the absence of tillage is permanent and the use of green manure crops to cover soils is widespread. The DPS not only have a positive impact on farmers cash flows, but also reduce the loss of nutrients, reducing emissions, and avoid erosion. This is an interesting case study for technology dissemination. Assunção et al (2019) examines in detail the adoption of DPS in Brazil and shows that geographical heterogeneity plays a major role in the diffusion process. The evidence is compatible with the importance of social learning mechanisms, in which farmers learn from each other when facing similar conditions, and the relevance of fine-tuning adjustments for adoption.

A substantial part of the public effort for technology dissemination takes the form of agricultural extension. In a large-scale experiment, Benyishay and Mobarak (2018) test the effectiveness of alternative approaches for technology dissemination for two new technologies (pit planting and Chinese composting) for maize farming across 120 villages in Malawi. Each village was randomly assigned to a different dissemination agent: (i) a government extension employee; (ii) a lead farmer; and (iii) five peer farmers. For each category, a subset of agents was exposed to small-performance-based incentives. The agents were expected to learn and communicate the technology of a group of farmers. The authors find that, without incentives, the program had disappointing results. Not even the farmers selected to act as dissemination agents were adopting the technology in the follow-up surveys. In contrast, when incentives are in place, the effects of the program on dissemination in villages served by peer farmers was the highest. These results suggest that social learning can be used to improve agricultural extension services – farmers tend to learn from each other. Results also illustrate the importance of incentives in implementing technical assistance interventions.

V. Conclusion

The world has profoundly changed the mode for the expansion of food production. Extensive practices, in which production increases were associated with larger areas, are being replaced by intensive practices, which relies heavily on yield gains for output growth. However, this is not a homogeneous process. There is still scope for increasing the pace in which these transformations are happening. On top of changes to allow

farmers to get closer to the technological frontier, there are also new production models expanding the technological possibilities, such as agro-forestry systems, regenerative agriculture or even alternative foods. The functioning of markets, the design of policies and the mechanisms for technology dissemination are key elements for implementing a zero-deforestation agenda, in which the expansion of agricultural production is solely driven by productivity gains. However, the optimal combination of initiatives for driving efficient land use is context specific and remain an open issue.

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