The effects on deforestation of conditional cash transfers: a study among the Khĩsêtjê Amazonian indigenous people

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HIGHLIGHTS

- Conditional Cash Transfers (CCTs) might change land-use decisions of indigenous people, increasing deforestation.
- Two agent-based models were adopted to evaluate that, varying in their assumptions about time allocation decisions.
- Results indicate that CCTs would likely decrease the time allocated to agriculture and the area deforested.
- Alternative assumptions about time allocation decisions changed results.
- The reduction in deforestation predictions was lower with the minimum working time assumption (Time Budget).

SUMMARY

Smallholders' contribution to Amazonian deforestation is currently increasing. In Indigenous Lands, changes in land uses might be partially due to the unintended effects of anti-poverty strategies, including the Conditional Cash Transfers (CCTs), which may promote the conversion of forests to agricultural lands. Despite that, little is known about whether and how CCTs affect long-term deforestation rates. Thus, this study has assessed whether CCTs influenced long-term land-use changes from forests to agriculture, considering alternative time allocation assumptions (i.e., Time Optimisation and Time Budget). Transfers from the Brazilian *Bolsa Família Program* to the Khĩsêtjê indigenous people of the Amazon were evaluated with two agent-based models. Results suggest CCTs will likely decrease the area deforested in the long term without changing Khĩsêtjê's population size. When market-purchased products replace local products, people's time allocated to agriculture is expected to fall. The intensity of CCT effects on deforestation varied according to time allocation assumptions, highlighting the importance of considering them carefully to improve the predictions from model simulations.

Keywords: market integration, small-scale communities, peasants, land-use change, socioecological systems, forest conservation

Os efeitos das transferências condicionadas de renda no desmatamento: um estudo com o povo indígena Khĩsêtjê da Amazônia

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A contribuição dos produtores familiares para o desmatamento da Amazônia está atualmente aumentando. Em Terras Indígenas, as mudanças nos usos da terra podem ser parcialmente devidas aos efeitos não intencionais de estratégias de combate à pobreza, incluindo as Transferências Condicionais de Renda (CCTs) que podem estimular a conversão de florestas em terras agrícolas. Apesar disso, pouco se sabe sobre se e como os CCTs afetam as taxas de desmatamento de longo prazo. Assim, este estudo avaliou se os CCTs influenciavam as mudanças de longo prazo no uso da terra de florestas para agricultura, considerando premissas alternativas de alocação de tempo (ou seja, Otimização de Tempo e Orçamento Temporal). As transferências do Programa Bolsa Família brasileiro para o povo indígena Khĩsêtjê da Amazônia foram avaliadas com dois modelos baseados em agentes. Os resultados sugerem que os CCTs provavelmente diminuirão a área desmatada no longo prazo, sem alterar o tamanho da população Khĩsêtjê. Quando os produtos comprados no mercado substituem os produtos locais, espera-se que o tempo das pessoas dedicado à agricultura diminua. A intensidade dos efeitos do CCT sobre o desmatamento variou de acordo com as premissas de alocação de tempo, destacando a importância de considerá-las cuidadosamente para melhorar as previsões das simulações em modelos.

Les effets des transferts conditionnels en espèces sur la déforestation: une étude chez les Khĩsêtjê amazoniens

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La contribution des petits exploitants à la déforestation amazonienne est en train d'augmenter. Dans les territoires autochtones, les changements dans l'utilisation des terres pourraient s'expliquer en partie par les effets involontaires des stratégies de lutte contre la pauvreté, notamment les transferts conditionnels en espèces (TCE), qui peuvent favoriser la conversion des forêts en terres agricoles. Malgré cela, on sait peu de choses sur l'impact des TCE sur les taux de déforestation à long terme. Cette étude s'est penchée sur le lien entre les TCE et la modification de l'utilisation à long terme des terres, de la forêt vers l'agriculture, en se basant sur des hypothèses alternatives d'allocation du temps (c'est-à-dire l'optimisation du temps et le budget temps). Les transferts aux populations autochtones Khĩsêtjê de l'Amazonie dans le cadre du programme brésilien *Bolsa Família* ont été évalués à l'aide de deux modèles d'agents. Les résultats indiquent que les TCE diminueront probablement la zone déboisée à long terme sans changer la taille de la population Khĩsêtjê. Lorsque les produits achetés sur le marché remplaceront les produits locaux, le temps que les gens consacrent à l'agriculture devrait diminuer. L'intensité des effets du TCE sur la déforestation variait en fonction des hypothèses d'allocation du temps, ce qui souligne l'importance de les prendre en compte avec attention pour améliorer les prévisions de résultats.

Los efectos de las transferencias monetarias condicionadas sobre la deforestación: un estudio entre el Pueblo Indígena amazónico Khĩsêtjê

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La contribución de los pequeños productores a la deforestación de la Amazonía está aumentando actualmente. En las Tierras Indígenas, los cambios en los usos del suelo podrían deberse en parte a los efectos no deseados de las estrategias de lucha contra la pobreza, como las transferencias monetarias condicionadas (TMC), que pueden fomentar la conversión de bosques a tierras agrícolas. A pesar de ello, apenas se sabe si las TMC afectan a las tasas de deforestación a largo plazo y cómo lo hacen. Por lo tanto, este estudio ha evaluado si las TMC han influido en los cambios de uso de la tierra a largo plazo de los bosques a la agricultura, considerando supuestos alternativos de asignación de tiempo (es decir, optimización del tiempo y planificación del tiempo). Las transferencias del programa brasileño *Bolsa Família* al Pueblo Indígena Khĩsêtjê de la Amazonía se evaluaron mediante dos modelos basados en agentes. Los resultados sugieren que es probable que las TMC reduzcan la superficie deforestada a largo plazo sin que cambie el tamaño de la población Khĩsêtjê. Cuando los productos comprados en el mercado sustituyen a los productos locales, se espera que el tiempo que la gente dedica a la agricultura disminuya. La intensidad de los efectos de las TMC sobre la deforestación varió en función de los supuestos de asignación de tiempo, lo que pone de manifiesto la importancia de considerarlas cuidadosamente para mejorar las predicciones de las simulaciones del modelo.

INTRODUCTION

Driven by markets on beef, crops, and timber (Dos Santos *et al.* 2021), deforestation in the Brazilian Amazon is mainly accountable for land-use changes in large properties (>500 ha) (Godar *et al.* 2014), albeit small-scale shifting cultivation drives transformations in riverine landscapes (Jakovac *et al.* 2017). However, recent evidence suggests an ongoing increase in smallholders' contribution to vegetation suppression (Godar *et al.* 2014, Kalamandeen *et al.* 2018) and a marked increase in deforestation rates inside indigenous and protected areas (de Oliveira *et al.* 2020). Such evidence is exemplified by a 34% increase between 2001-2007 and 2008-2014 in the number of small land clearings (< 1 ha) in the entire Amazon, a deforestation pattern often associated with smallholders' activities (Kalamandeen *et al.* 2018). Therefore, the observed changes have boosted calls for conservation measures targeting small clearings (Godar *et al*. 2014, Kalamandeen *et al*. 2018) to improve understanding of smallholders' deforestation behaviour and its drivers (Schielein and Börner 2018).

In the Brazilian Amazon, one reason given to explain transformations in shifting cultivation dynamics is the sharp increase, over the last decade, in demand and prices of cassava flour (Jakovac *et al.* 2016). This integration into agricultural markets is an essential driver of social changes in the Amazon (Houck *et al.* 2013, Peralta and Kainer 2008) and has had implications for land use and land cover among riverine communities (Jakovac *et al.* 2017). While similar changes are expected to occur when largely autarkic indigenous societies (i.e. almost or completely self-sufficient societies with little or no exposure to the market economy) integrate into markets, the evidence is disputable as to whether any form of market exposure will lead to more (Gray *et al.* 2008, Klepeis and Vance 2003) or less deforestation (Ferraro and Simorangkir 2020, Vasco *et al.* 2018). For instance, evidence from five indigenous communities in the Ecuadorian Amazon indicated that households closer to markets were more likely to engage in agricultural trade, driving the expansion of the cultivated area (Gray *et al.* 2008) and, hence, deforestation. In contrast, more access to off-farm wages – another form of integration into the cash economy – correlated with less deforestation for agriculture by indigenous people and other smallholders in another Ecuadorian Amazon study (Vasco *et al.* 2018). The latter authors offered two explanations. First, higher earnings reduced the need to clear forests to expand agriculture, and second, off-farm jobs reduced the time available to work in agriculture.

These examples illustrate the conclusion reached by decades of studies on the implications to land and natural resource use when indigenous societies are exposed to the cash economy. In short, alternative forms of access to markets (or definitions of market integration) may produce different outcomes (Godoy *et al.* 1997, 2005, Lu 2007). Consequently, understanding how indigenous people and other smallholders respond when exposed to various cash sources is warranted.

Conditional Cash Transfers (CCTs) are such a form of market integration. CCTs have become increasingly popular worldwide (Fiszbein and Schady 2009) as part of global efforts to fight poverty (Das *et al.* 2005, Soares and Sátyro 2009). The strategy relies on transfers from governments to low-income families, conditional on household investments in human capital, mainly health and schooling (Fiszbein and

Schady 2009). In Brazil, the *Bolsa Família Program* (BFP) benefits the largest number of families in developing countries worldwide (Lindert *et al.* 2007). Poor and extremely poor families with children and/or pregnant women receive a variable cash income from the Brazilian government. In return, they must guarantee children's school attendance and health monitoring of the family children and pregnant women.

CCTs such as this benefit mainly rural populations, as approximately 76% of the world's poor inhabit rural environments (Dercon 2009). Since indigenous populations are often cash poor (Hall and Patrinos 2012), CCTs also increase indigenous people's exposure to the market economy. Likewise, in Brazil, among the BFP beneficiaries, 21% are rural families (MDS 2017), although only 15% of the country's population inhabits rural areas (IBGE 2016). For indigenous people, this difference is even higher, as the proportion of indigenous families benefiting from the BFP (0.84%) (MDS 2017) doubles the national rate (0.40%) (IBGE 2010).

Since market integration may affect natural resource use, CCTs may have unintended consequences on forest conversion to agricultural lands in the Amazon. Understanding the effects of CCTs on indigenous peoples' lands matters because their territories occupy around 24% of the whole Brazilian Amazon (estimated from Nogueira *et al.* 2018). Despite earlier calls to investigate this issue (e.g., Sathler *et al.* 2018), evaluations of the consequences are rare and conflicting, as both reductions (Ferraro and Simorangkir 2020, Malerba 2020) and increases in deforestation have been observed (Alix-Garcia *et al.* 2013, Iwamura *et al.* 2016). This article contributes to this debate by investigating whether CCTs (i.e., BFP) may affect forest conversion to agricultural land, using two agent-based models of the Khĩsêtjê indigenous people (in the south-eastern Amazon). Additionally, this study evaluated the mechanism behind these changes by analysing the CCT effects on population size and time allocated to subsistence activities (i.e., agriculture, hunting, and fishing).

Decision-making assumptions

Deforestation studies through modelling depend on the simulation of people's decision process. Therefore, comprehending the decision-making assumptions considered in modelling studies is fundamental to evaluating their outcomes. Among previous studies investigating CCT effects on deforestation, Iwamura and colleagues (2016) adopted a predictive agent-based model to investigate the potential outcomes of CCTs on natural resource exploitation and land uses, more specifically, on agriculture and hunting. Their study predicted that, in the long run, cash transfers would lead to more agriculture-led deforestation, which would partially derive from the population growth. As a modelling study, this evaluation relied on expectations about how households decide to allocate their daily time. The model assumed household decisions were fundamentally rational, which implicitly assumes that decisions involve a process of conscious and consistent choices motivated by individual preferences (de Jonge 2012, Monroe 2001, Simon 1995). In Iwamura *et al.*'s model (2016), an individual's preference was defined as the intention to satisfy a specific energy requirement, which is one of the most common rules adopted in socioecological models (see An's (2012) review). Despite this assumption's popularity, two aspects were disregarded. First, the particularities of small-scale householders' time allocation decisions were neglected, as they might consider other individual preferences besides often violating rational principles. Observational studies demonstrate that, in communities directly dependent on natural resources, people's decisions frequently rely on a goal-drudgery balancing process rather than on energy maximisation (e.g., Chayanov 1966, McKinnon 1976, Umar 2014, Valencia Mestre *et al.* 2020). Hence, people seek to balance income with the drudgeries of work (Time Optimisation Premise, hereinafter Optimisation), as proposed in the Chayanovian theory (Ellis 1993).

Additionally, smallholders may violate the rational principle of fungibility, which assumes that a resource, like money, is perfectly replaceable by another good of the same kind (Thaler 1999) (e.g., a dollar from a salary is a perfect substitute for a dollar from a gift). Previous evidence demonstrates that smallholders (e.g., Duflo and Udry 2004, Villa *et al.* 2010) mentally allocate resources to alternative categories or "accounts" (e.g., salary, livestock sale, gifts). Each account serves a different expense type of goods or services (e.g., food, luxury goods, education-related products), as proposed by Thaler in the Mental Accounting Theory (Thaler 1990, 1999). The tendency to mentally split resources into categories was also observed when time was the available resource (Amato *et al.* 2017, Rajagopal and Rha 2009). Which suggests people take decisions by dividing their time into at least two categories – work and non-work – and by establishing time budgets for each type (Rajagopal and Rha 2009). For example, they might distinguish a minimum amount of time (e.g., 6 hours daily) for devoting to work (Time Budget Premise, hereinafter Budget).

Adopting alternative theoretical assumptions about how people take time allocation decisions may change earlier predictions about the long-term impacts of CCTs on the area deforested for agriculture. The reason is that such assumptions influence the expected amount of time spent on subsistence activities, such as agriculture, and may thus transform the area deforested. In modelling studies, defining decision-making assumptions is paramount. Hence, assessing alternative model predictions is essential to understand better whether CCTs to indigenous inhabitants of forested areas may contribute to more deforestation in the long run. Thus, this study investigated whether CCTs (i.e., BFP) may affect the long-term conversion of forests to agricultural lands by the Khĩsêtjê, assessing the consequences of adopting two alternative premises – Optimisation *versus* Budget – on the size of the deforested area.

The study considered two hypotheses. First, CCTs should reduce the area deforested for agriculture since the time allocated to agricultural work will likely decrease. Second, the intensity of the CCT effects will vary depending on the assumption considered. If people decide according to an Optimisation Model, higher levels of monetary income will likely decrease the working time required to obtain the target level of energy consumption. When aimed at reducing the drudgeries of work, the time dedicated to agriculture should also decrease and, consequently, the expected deforested area will likely shrink. Instead, suppose a Budget Model guides the time allocation decisions of indigenous households. In that case, reductions in the time dedicated to agriculture due to CCTs will likely be substantially smaller or even null. This trend could occur when people establish a minimum time budget for how much they should work on a day. Consequently, there would be little or no reduction in deforestation. The evaluation of changes in deforestation to test these hypotheses also considered population size and time allocated to subsistence activities (i.e., agriculture, hunting, and fishing) to assess whether demographic changes and/or variations in agricultural effort could be the mechanism behind changes in forest conversion).

METHODS

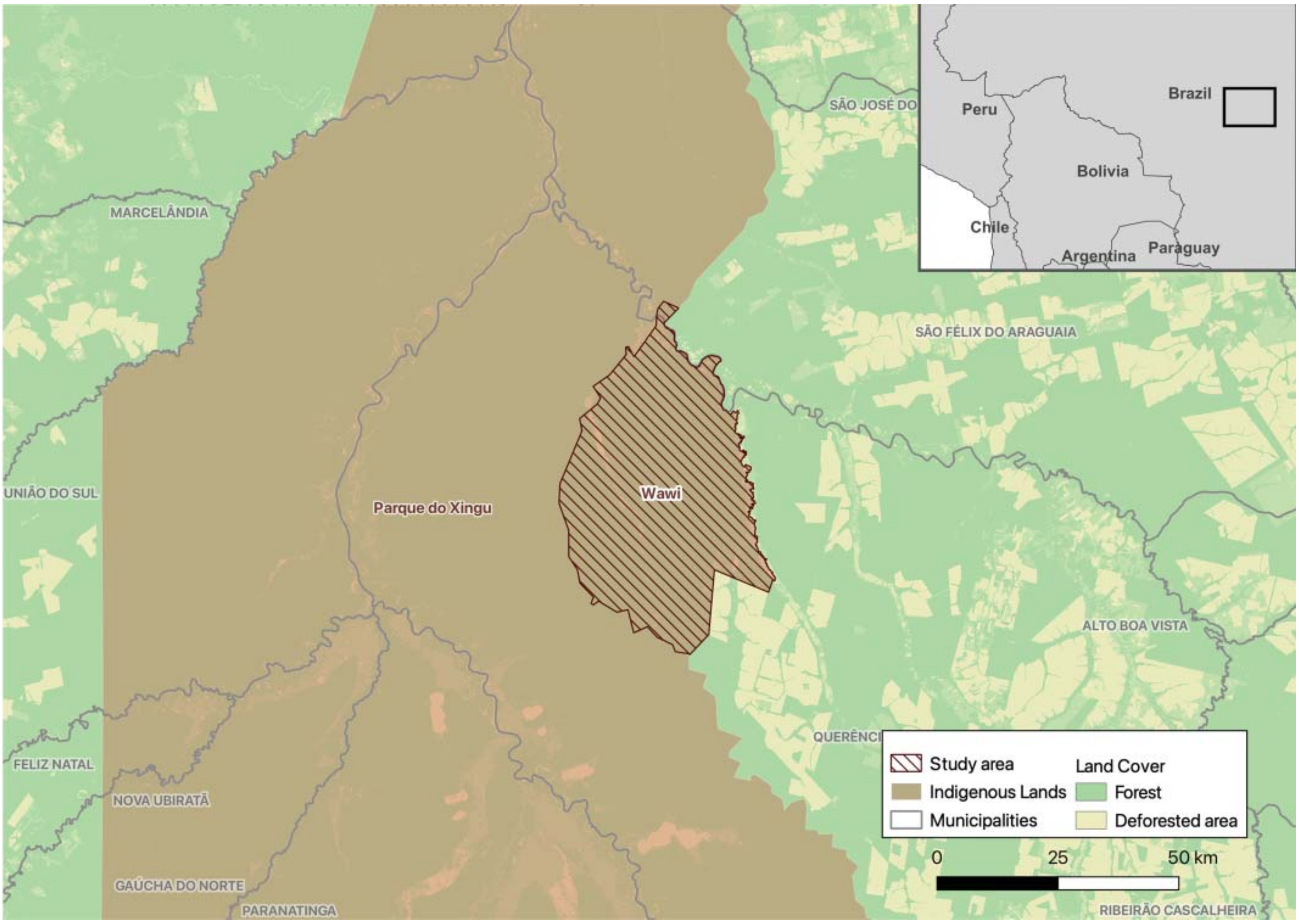
Population studied

The Khĩsêtjê are a typical indigenous group of ~510 people inhabiting the Wawi Indigenous Land in the Brazilian state of Mato Grosso, South-eastern Amazon (Figure 1). Wawi is a territory of 150,000 ha, of which 88% are primary forests and 12 % are secondary forests (ISA 2020). Local deforestation is low, with only 15 ha cleared in 2017, in sharp contrast to the surrounding lands deforested by agribusinesses (ISA 2020).

The Khĩsêtjê, like other traditional populations in Brazil (i.e., *caboclos*, *quilombolas*) are highly dependent on forests to obtain food and other resources (e.g., wood) from hunting, fishing, and gathering timber and non-timber forest products, but they mainly rely on swidden agriculture. Activities are gender divided: while men hunt, fish, and prepare and maintain the agricultural plot (i.e., opening, cleaning), women harvest agricultural products, convert cassava into flour, and are responsible for domestic chores (e.g., children's care and cooking) (ISA 2011). The effort invested in these activities varies throughout the year, as subsistence activities are subject to climatic seasonality. Households comprise 1-7 nuclear families (i.e., parents and children) and share all food products.

Subsistence income is complemented by cash income, mainly from: (i) the sale of handicrafts, honey, and pepper; (ii) paid jobs (e.g., teacher and school employees by the Education State Secretary of Mato Grosso); and (iii) federal government CCTs, non-contributory old-age pensions, and other social security benefits. The CCT to the Khĩsêtjê is the BFP, locally implemented in 2009. Although shared within

FIGURE 1 *Map of Wawi Indigenous Land (study area). Background colors show the land cover in 2018, based on MapBiomas shapefiles. Yellow represents deforested areas and green represents forest areas*



the household, women receive most BFP transfers (97%). The amount of each transfer varied between USD15.73 and USD111.75 per month during fieldwork. The number of beneficiaries per household ranged from 1 to 7.

Modelling approach

Since CCTs to the Khĩsêtjê only began in 2009 an observational study to test the long-term deforestation trends was not feasible. Hence, we adopted computational modelling to test alternative scenarios (Winterhalder 2002). We developed two Agent-Based Models (ABMs) to represent the most populous Khîsêtjê village (i.e., 29 households, 35 houses, 384 people). Both ABMs were identical, except for the decision-making rules. Models were implemented in Python version 6.0.3, using the Jupiter notebook in the Anaconda navigator.

ABM is a bottom-up approach that reproduces individual social actors (agents) integrated within a dynamic environment through pre-defined rules (An 2012). This tool is appropriate to study small-scale communities, such as the Khîsêtjê, because of its power to model individual decisions, incorporating interactions (e.g., relationships among households and between households and the environment) and feedback. For example, feedback encouraging deforestation could arise if deforestation reduced bushmeat availability, leading to less hunting and, consequently, more time invested in agriculture, hence, more deforestation.

To represent the Khîsêtjê, the ABMs worked in annual cycles, divided into five processes: (i) demographic change, (ii) subsistence activities, (iii) sharing, (iv) energy checking, and (v) ecological succession. Demographic changes involved transformations through birth, ageing, marriage, and death, all randomly attributed and defined by age-specific rates. In the subsistence process, households decided how much time to allocate to three activities: agriculture, hunting and fishing. Households also cleared forests for their agricultural plots, with size directly proportional to a household's time allocated to agriculture.

We incorporated two decision rules in ABMs: (i) Optimisation, based on Chayanovian Theory (Chayanov 1966), and (ii) Budget, based on Mental Accounting, precisely the principle of non-fungibility (Thaler 1990, 1999).

In the Optimisation model, households aimed to minimise their working time while satisfying their target energy consumption. A maximum of 35% of energy was allowed from animal-sourced food (i.e., hunting or fishing) because evidence suggests that humans may not tolerate diets with above rates of animal protein intake (Cordain *et al.* 2000). The model calculates the target energy consumption by summing up the amount of food expected from subsistence activities (i.e., agriculture, hunting, and fishing) and the amount purchased with CCT income. Since time allocation decisions aim to minimise household working time, they allocated less time to subsistence activities when households obtained more energy from CCT income. For simplicity, all same-gender householders worked equal amounts of time, and households harvested all crops available each year. Rule decisions were set with the Lagrange multiplier, a mathematical optimisation method for finding local minima/maxima (Hoffmann and Bradley 2010).

In the Budget model, people mentally divided time into alternative non-interchangeable categories and established a budget, specifically, a minimum working time. Decision rules in this Budget model had two steps. First, as in Optimisation, households set the amount of working time necessary to satisfy their energetic needs, subject to 35% animal-sourced food constraints. Households then compared this working time with their minimum working time budget, which was assumed to be culturally defined and equal for all households (i.e., four working hours/per day for each person). If the working time necessary to satisfy a household's needs was lower than the minimum working time budget previously set, households worked the four hours (the minimum working time budget). Otherwise, households worked the time necessary to satisfy their household needs, as in the Optimisation model.

The quantity of food (i.e., energy consumption) that each household obtained annually depended on the time dedicated to subsistence activities and varied according to random factors. Households with food shortages tried to receive food donations from those with food surpluses during the sharing process. Households engaged in a delayed reciprocity process (Bliege Bird and Bird 1997), and, thus, those that received donations tried to produce more food in the following years to share in return. After the sharing process, the energy checking process began, and households computed the total energy consumption obtained. Those who did not meet the minimum energy consumption (i.e., 689,850 kcal/year per member – FAO n.d.) left the simulation.

The models simulated demographical, production and consumption dynamics with parameters that represented actual system characteristics (e.g., natality and mortality rates, subsistence success rates, and kilocalories intake). Whenever possible, we established parameter values using field data. When this was impossible, the estimations of parameter values came from the literature. Field data were collected in the most populous village during three periods (i.e., February–March 2016, January–March 2017, and September–October 2018), using face-to-face surveys and direct observational techniques (i.e., weight day, time allocation and agricultural plot measurement – Cunha 2020).

Both developed models tested the long-term effects of CCTs from the BFP, assuming transferences provided the only source of cash for the population. In the models, households could use all or part of their CCT income to purchase food and, thus, increase their energetic consumption. When the household did not invest all CCT income in food, we considered they invested the spare money in other consumer goods. Thus, there was no money surplus since the Khĩsêtjê very rarely had savings (Troncarelli 2018). We assumed that only the CCT income invested in food affected household decision-making. Therefore, to analyse the effects of CCT income, we varied the share used to purchase food. All households spent the same CCT percentage on food, but each one received a specific amount of money. The income varied randomly, ranging from the minimum and maximum CCT *per capita* income observed in field data (i.e., dividing the sum of all CCT income received in the household by the number of household members).

Results were evaluated using two approaches: (i) Last Year's results (LR) estimated the outcome in the final year simulated, whereas (ii) Annual Results (AR) referred to each simulated year. In both approaches, results represented the average of 100 simulations. Each set of 100 simulations regarded one CCT percentage and one decision model (i.e., Optimisation and Budget). Thus, to compare the effects of 10 CCT percentages, we ran 2000 simulations, corresponding to 1000 simulations for the Optimisation model (i.e., 100 simulations per CCT percentage) and 1000 simulations for the Budget model.

Each simulation lasted 40 years using both models. Models were run for more extended periods to avoid transitory behaviours since, to handle transients, the behaviour and reactions of the modelled system need representation with greater accuracy, which is challenging for social systems.

This article aimed to investigate whether CCTs may affect deforestation in agriculture and to evaluate the possible mechanism behind these changes (e.g., population size or average annual working time per individual). Therefore, we visually compared two variables in the LR analysis: total deforested area (hectares) and total population size. We measured both variables at the last year simulated (40th year) to investigate the effect of 20 CCT percentages (ranging from 0% to 100%, considering a 5% increase).

The AR analysis focused on the annual variation of three variables: total deforested area (hectares), total population size, and the yearly average of working time per individual (hours/individual). We visually compared every year's values of these three variables when adopting six CCT percentages (i.e., from 0% to 50%, considering a 10% increase).

RESULTS

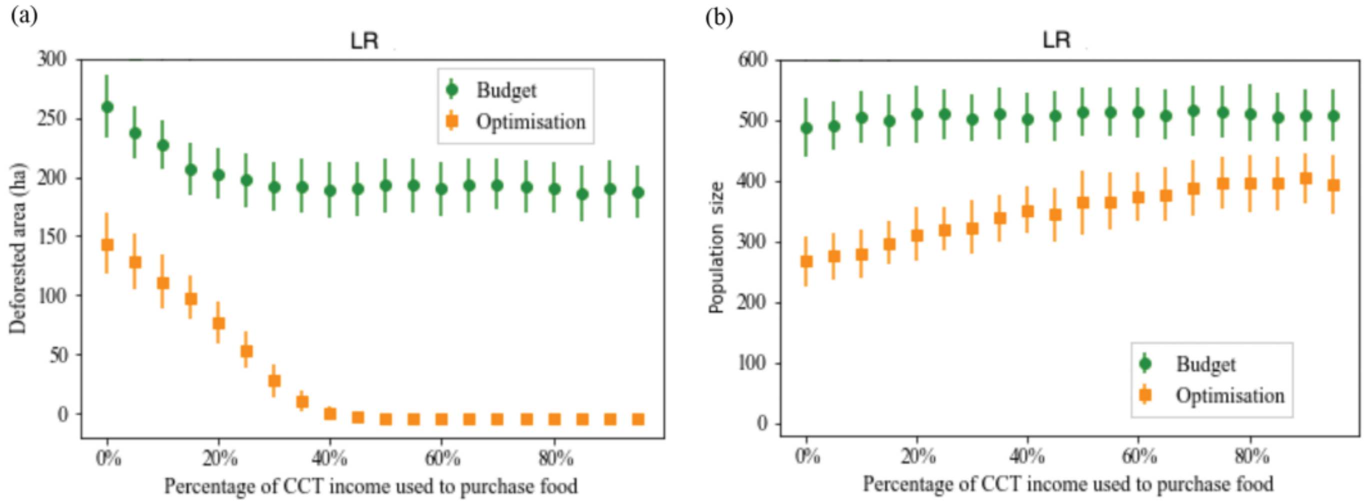
We first present LR results because they help understand the general effect of CCT income on the: (i) area deforested and (ii) population size. Then, we present AR results to evaluate the dynamics over time.

LR analysis showed that the total area deforested decreased with higher levels of CCT percentages (Figure 2a), but the reduction depended on the model adopted. For all CCT percentages, the deforested area predicted by the Optimisation model was smaller than the estimation with the Budget model. Notably, only the Optimisation model predicted that deforestation would fall to near-zero when people used 40% or more of the CCT income to purchase food.

In both models, CCT effects on the final size of the indigenous population (Figure 2b) differed from those observed on the total deforested area (Figure 2a). While higher percentages of CCT income correlated with a lower proportion of deforested area per person, no effect on population size was observed in the Budget model. Instead, in Optimisation, a slight increase in population size with higher percentages of CCT income was observed. Although initial populations were the same, the Optimisation population became considerably smaller than the Budget population. This outcome happens because, in Optimisation, households work the minimum amount of time necessary to fulfil energy intake. Hence, they became more subject to food shortages due to random variations in production, resulting in population reduction.

The second analytical approach – AR – described the annual outcomes of three variables: total area deforested, total population size, and yearly average of working time per individual. The total area deforested represented both the area cleared in the current year and all areas cleared in the previous years that did not complete the vegetation succession (i.e., partially regrown forests).

FIGURE 2 *(a) Deforested area (hectares) and (b) population size obtained in the last year simulated (40th year) for each percentage of CCT income used to purchase food*



For all variables, AR evaluations indicated that differences across CCT percentages observed in LR were mainly due to changes in the variables' values in all years instead of differences in the variables' dynamics over time (Figure 3 and Figure 4). This finding implies no noticeable variations over the simulated years in the shape of the curves defining the variables, but only in their values.

The curve defining the area deforested over time was different in each model, although no variation in their shape was observed across CCT percentages. In the Optimisation model, differences in the deforested areas across CCT percentages were seen in the first five years of simulation. After this period, however, the size of the deforested area stabilised (Figure 3a). The total deforested area grew linearly during the first five years, with a steeper growth observed with lower CCT percentages. After the fifth year, in all percentages, the area deforested stabilised. The only exception was the 50% of CCTs when the deforested area remained zero throughout the simulation.

In the Budget model, differences in the deforested area across CCT percentages were observed only after the fifth year of simulation (Figure 3a). In contrast, the area deforested grew equally for all CCT percentages before this period. After five years, the deforested area kept increasing, but at a slower pace and with different rates for each CCT percentage (i.e., higher growth rates for lower CCT percentages). Differences among growth rates were smaller with higher CCT percentages and, due to that, the same curve was observed with 30%, 40%, and 50%.

In both models, a transition point in the fifth year of the simulations was noted (Figure 3a). Initially, total deforestation grew linearly; after the fifth year, growth stabilised or increased at a lower rate. According to interview data, this transition point might result from the fallow land period, which lasted at least five years. Therefore, after these five years, areas already deforested could be reused for agriculture, probably reducing the deforestation of primary forests.

The results of the AR analysis also showed that population dynamics differed from the deforested area dynamics and varied between the two models (bearing in mind that the initial population size corresponds to the most populous village: 380 people) (Figure 3b). In Budget, the number of individuals in the community grew linearly during all years, without significant differences across CCT percentages. Conversely, in the first five years of the Optimisation model's simulations, a decrease in the population size was observed and, subsequently, a population increase, which was slightly higher for lower CCT percentages. Therefore, only Optimisation variations in CCT percentages affected the indigenous population size. This behaviour might result from food shortages and sharing behaviour incorporated in the model. Since households worked the minimum possible share of time in the Optimisation model, they were probably more affected by food shortages which negatively impacted population sizes. When households received food gifts, they worked longer to have food surpluses and to be able to reciprocate. Increased working time led fewer households to suffer from food shortages, allowing the population to grow.

Lastly, in both models, higher percentages of CCTs reduced the average annual time allocated per individual to agriculture (Figure 4a). Reductions in agricultural working time were more significant in the Optimisation model. This observation reinforces the view that CCTs change the proportion of deforested areas per individual in the community. Since the agricultural plot area was directly proportional to agricultural working time, less time dedicated to agriculture resulted in smaller agricultural plots and, consequently, less deforestation. No effect was observed on the average annual time allocated per individual to hunting and fishing (Figure 4b).

DISCUSSION

This study evaluated the unintended effects of CCT implementation in an indigenous society on land-use changes in the Amazon. The results contribute to the debate of whether this form of market exposure adversely impacts forest cover, with three main findings: (i) CCT income likely reduces deforestation for agriculture, providing one more example of the conflicting literature regarding CCT effects; (ii) the degree of CCT effects depends on people's decision-making process; and (iii) the observed deforestation reduction is probably caused by lower agricultural effort due to the replacement of local agricultural goods by purchased ones.

FIGURE 3 *(a) Deforested area (hectares) and (b) population size obtained per year simulated for each percentage of CCT income used to purchase food*

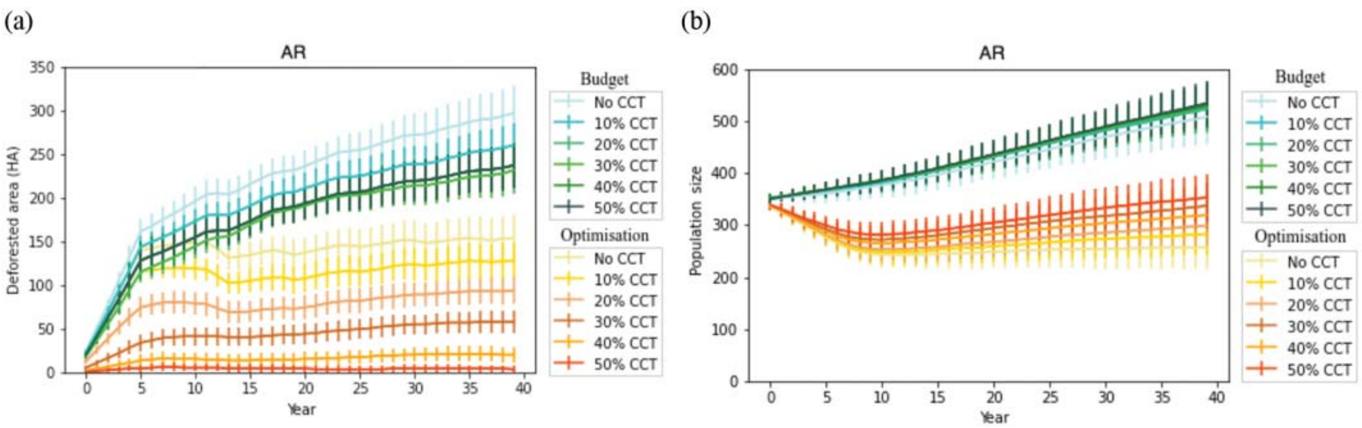
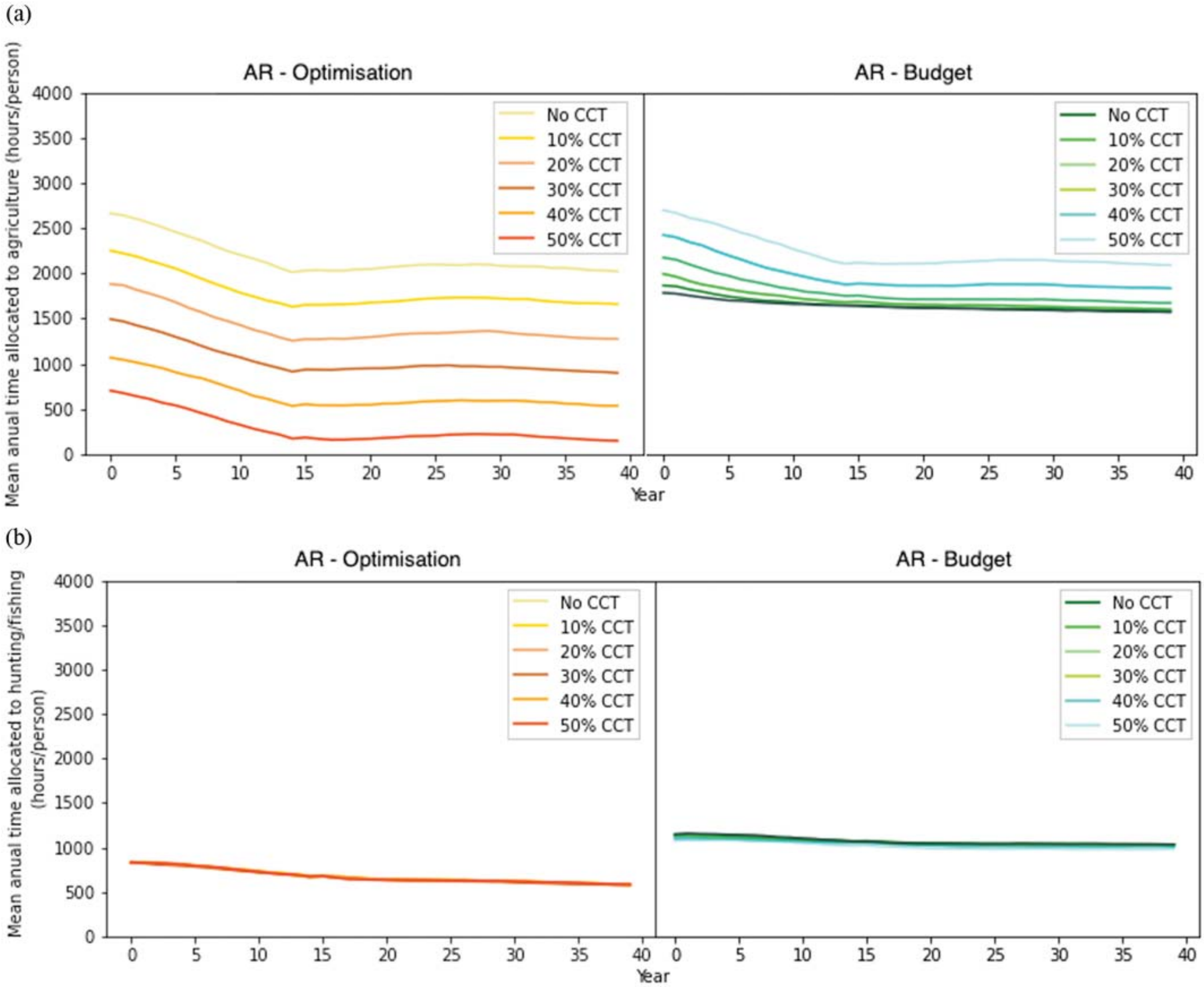


FIGURE 4 *Average time (hours/individual) annually allocated to (a) agriculture and (b) hunting and fishing per year simulated for each percentage of CCT income used to purchase food*



This study focused on CCT income, a non-effort source of cash, as conditionalities for receiving these transfers do not require any labour or time investment, at least within the Brazilian indigenous territories context. Program conditionalities that could have implied time trade-offs – such as the demand for children and teenagers' school attendance – did not affect the outcomes since both models assumed only adults worked on subsistence activities. Therefore, the results here might equal what would have been expected with other non-effort income sources, such as non-contributory old-age pensions and other social security benefits.

Deforestation decreases

Model simulations indicated that higher CCT incomes in indigenous households likely reduce forest conversion to agricultural land. This finding suggests CCT income probably does not explain the recently observed increase in deforestation rates inside indigenous territories (e.g., de Oliveira *et al.* 2020). To our knowledge, no previous empirical investigation assessed the effects of CCTs on deforestation considering the changes in the agricultural practices of indigenous or other traditional rural populations. Previous studies only assessed CCT effects on traditional people's deforestation using a modelling approach, indirect information from specialists' perceptions (Iwamura *et al.* 2016, Van Vliet *et al.* 2013) or empirically analysed this effect in non-traditional populations (Alix-Garcia *et al.* 2013, Ferraro and Simorangkir 2020, Malerba 2020). Results from these studies suggest two possible outcomes.

First, in agreement with the findings here, at least three articles have suggested that higher CCT incomes lead to lower deforestation rates (e.g., Ferraro and Simorangkir 2020, Malerba 2020, Van Vliet *et al.* 2013). For example, qualitative information from open question interviews with specialists suggests that CCTs help stabilise forest-agriculture frontiers in lands inhabited by indigenous and other traditional *caboclo* communities of the Brazilian Amazon (Van Vliet *et al.* 2013). Additionally, when considering CCT effects on deforestation of rural areas (not necessarily occupied by traditional societies), at least two empirical studies support the findings here (i.e., Ferraro and Simorangkir 2020, Malerba 2020). Using high-resolution maps, Malerba (2020) compared the area deforested in Colombian municipalities enrolled in a CCT program with those eligible for transfers that did not register. In rural towns where CCTs were in place, the author found that deforestation decreased by approximately 0.5% compared to the counterparts where the CCT was not in place. Similarly, Ferraro and Simorangkir (2020) compared the deforestation trends of Indonesian rural villages before and after CCT implementation. Using panel data on annual forest cover loss and a quasi-experimental counterfactual design, the authors estimated that implementing a CCT program reduced tree cover loss by 30%. Similar to the findings here, both previous investigations attributed lower deforestation levels to the substitution of deforestation-sourced consumption with market-purchased goods.

However, the second line of evidence differs from the findings here. Two previous publications concluded that implementing CCTs affected local consumption dynamics and, consequently, increased the area deforested (Alix-Garcia *et al.* 2013, Iwamura *et al.* 2016). By exploiting a discontinuity in community-level eligibility, Alix-Garcia *et al*. (2013) observed a positive relationship between CCT income and deforestation in non-traditional rural villages in Mexico. The authors explained this trend as originating from more demand for two land-intensive goods: milk and beef. This reason may justify the opposite results to the findings here since the Khĩsêtjê do not produce land-intensive goods.

The second study, by Iwamura *et al*. (2016), investigated indigenous communities from the Guyanese Amazon. The authors evaluated the unintended effects of CCT implementation on animal abundance (due to hunting) and forest conversion into agriculture with a computational model. Their evidence suggests more conversion derives from growth in the average area deforested per household and the community population size (Iwamura *et al.* 2016). Equivalent to this study, their model linked population dynamics to food intake; specifically, they analysed emigration associated with low food intake. In contrast to this study's models, Iwamura *et al*. (2016) ignored time allocation in their decision-making model, an aspect that may explain the contrasting findings. Over there, the authors disregarded that CCTs may lead to less time allocated to work. When reductions in time use are ignored, the effects of CCTs on population growth are noticably higher. The reason is, without lowering effort and consequently decreasing agricultural plot sizes, CCTs increase the amount of food available and lower emigration rates, therefore explaining why population size increased in their study.

The importance of the decision-making process

The disparities in predictions between this study and Iwamura *et al*.'s (2016), as well as between Optimisation and Budget models, highlight the pivotal role of decision-making assumptions in model results. In other words, even though both models proposed here reduced deforestation, the intensity of their effects differed: the Optimisation model predicted smaller deforested areas for all percentages of CCT income used to purchase food. Thus, these differences reinforce the importance of understanding how indigenous people and other non-W.E.I.R.D. societies (i.e., non-Western, Educated, Industrialised, Rich, and Democratic societies) decide since there is substantial variability in reasoning styles across cultures (Henrich *et al.* 2010). This aspect is paramount when adopting computational models to evaluate the outcomes of any public policy, as competing assumptions may lead to substantially different inferences.

The mechanism behind reduced deforestation

This study's findings suggest CCTs may reduce the average area deforested per person by decreasing the time allocated to agriculture without lowering the population size. Investigations with other traditional populations, such as *Quilombolas* (Adams *et al.* 2013, Thorkildsen 2014) and *Ribeirinhos* (Piperata *et al.* 2011b), are in accord with these results. Over these populations, BFP transfers reduced the time invested in agriculture (Adams *et al.* 2013, Thorkildsen 2014), hunting and fishing (Piperata *et al.* 2011b). Yet, this comparison has limits because previous studies did not estimate time investments directly. In fact, except for Piperata *et al*. (2011b), previous research relied on people's perceptions through qualitative interviews and participant observation. As these methods are subject to unconscious biases, both from participants and observers, they may lead to inaccurate time allocation estimates (Gross 1984). As no other studies investigated such CCT effects, at least to our knowledge, further comparisons are impossible.

The mechanism explaining declines in the time allocated to agriculture observed here reflects the substitution of locally-produced food for purchased products. Again, such an effect has previously been documented in the traditional communities mentioned above (Adams *et al.* 2013, Piperata *et al.* 2011a,b, 2016), while other studies failed to observe such substitution (e.g., De Lima *et al.* 2020).

One limitation of the ABMs proposed here is the non-incorporation of the differences in distance to access market products. When this occurs, we would likely expect weaker CCT effects on deforestation in locations far from markets, as replacing local products with purchased goods becomes more expensive. Indeed, using empirical data, previous studies analysed whether CCT effects on deforestation varied according to market proximity. While Ferraro and Simorangkir (2020) found that CCTs reduced deforestation in communities closer to markets more substantially, Malerba (2020) failed to observe statistically significant effects of such distance on deforestation. Yet, the latter author also analysed whether CCT effects on household consumption varied due to market proximity. They found that households closer to markets tended to consume more land-intensive goods, potentially affecting deforestation trends. Since the available evidence of the relationship between CCTs and deforestation is still scant, a deeper understanding of the unintended effects of CCT income is needed.

CONCLUSIONS

This article began by asking whether the implementation of CCTs affected the long-term conversion of forests to agricultural lands, and if so, whether CCTs contributed to increasing or decreasing deforestation rates inside indigenous territories. Two hypotheses were considered.

In the first hypothesis, CCTs would reduce forest conversion into agricultural lands in the long term. Both models' predictions corroborated this hypothesis. Results indicated reduced deforestation is a consequence of less time invested in agriculture since there were no observable changes in Khĩsêtjê's population size. Therefore, CCTs are unlikely to drive more deforestation in indigenous territories, consistent with two previous findings with other countries' CCTs (i.e., Ferraro and Simorangkir 2020, Malerba 2020). This finding, however, contrasts with an earlier model targetting Amazonian indigenous communities from Guyana (i.e., Iwamura *et al.* 2016), which predicted an increase in deforestation due to population growth affected by CCT implementation. This divergence is most likely evident because Iwamura's model disregards the CCT effects on time allocation (i.e., possible reduction in households' working time due to these transfers).

The second hypothesis stated that declines in subsistence working time due to CCTs – and, hence, less deforestation – would likely vary depending on decision-making assumptions. The results here confirm this hypothesis, as more substantial effects were observed in the Optimisation model when compared to the Budget model. This finding highlights the importance of understanding the actual behaviours of families and individuals, particularly when it comes to simulating or evaluating the effects of interventions with Indigenous and other non-W.E.I.R.D. societies. Evidence indicates these societies present considerable variation in characteristics, including psychological and decision-making attributes (Henrich *et al.* 2010). Therefore, transposing decision models from western educated societies to these societies is probably inadequate.

The implications of this study's results for socio-environmental conditions in indigenous territories are two-fold. On the one hand, deforestation decreased – a positive outcome. On the other, replacing local products with market-purchased industrialised food might increase the environmental footprint of indigenous populations. The rationale is that purchased products often come from land-intensive activities associated with substantial deforestation and long-distance transportation. Moreover, replacing locally-produced food with processed alternatives may drive nutritional changes and increase the chances of chronic health problems (Hackett *et al.* 2020). Although nutritional transitions are already evident among certain indigenous or traditional forest societies (Byron and Reyes-García 2021, De Lima *et al.* 2020), it is still debatable whether CCTs are responsible for that (De Lima *et al.* 2020).

Findings reported here could be subject to at least three limitations, which call for further investigations. First, the models proposed did not detail how access to market products occurs. As marketplaces are absent within the Khĩsêtjê territory, local inhabitants must reach the nearest town (5-6 hours' drive away) to receive cash transfers and to purchase products. Thus, acquiring market-purchased goods takes time and has high transportation costs, two aspects that might discourage product substitution. Supposedly, the effects of CCTs on deforestation could then be lower. Nonetheless, there is still a knowledge gap about how the CCTs effects on deforestation varies according to market proximity.

Second, this study disregarded other types of cash income received by the Khĩsêtjê, such as effort-based income sources. Other monetary sources might produce contrasting effects on deforestation due to their characteristics. For instance, effort-based income, such as salaried jobs or the sale of natural resources and crafts, creates time use trade-offs which reduces the time available to allocate to subsistence activities. Therefore, potential associations between CCTs and other cash income sources could lead to different results from those presented here.

Finally, food purchases were the only use for CCT income incorporated in the models,yet in real-world settings, this income source is also spent on other products and with different purposes, such as acquiring tools that facilitate subsistence activities. The purchase of specific agricultural tools (e.g., power weeder) or inputs (e.g., fertilisers) may increase productivity and affect forest conversion into agricultural land. Nevertheless, this effect is likely negligible since there were no such purchases during fieldwork nor reports among Amazonian indigenous peoples in previous studies.

Modelling studies, like this one, are great tools to examine the potential outcomes of public policies such as CCTs. Yet, the main lessons from these models go beyond estimating the long-term consequences of policies. Instead, they help understand scenarios across various assumptions and policy formats. Accordingly, this investigation also highlighted the crucial role of understanding how indigenous and other small-scale societies make decisions in order to improve policy evaluation.

ACKNOWLEDGMENTS

This study was funded by the Coordination for the Improvement of Higher Education Personnel (CAPES) – Finance Code 001 through a scholarship to P. Reis Cunha, and by a research grant from the São Paulo Research Foundation-FAPESP (Project #2016/12803-9) to C. Morsello

This study was approved by the National Indian Foundation (FUNAI, in Portuguese) (Licenses nº 94/AAEP/PRES/2018 and 289/2019/AAEP/FUNAI) and by the Ethical Committee for Research in Human Beings of the School of Arts, Sciences and Humanities of the University of São Paulo (Licences nº CAAE: 51133815.6.0000.5390, 97750818.9.0000.5390 and 06742818.6.0000.5390).

We thank, for useful comments and suggestions on previous drafts, two anonymous referees, T. Fonseca-Morello, S. A. de Sousa, C. B. Pereira, C.D. Carrilho and I.T. Ribeiro; for assistance and fieldwork company, L.T. Troncarelli and, most importantly, the Khĩsêtjê for accepting this research, providing excellent hospitality, and sharing knowledge during our stay at Khikatxi.

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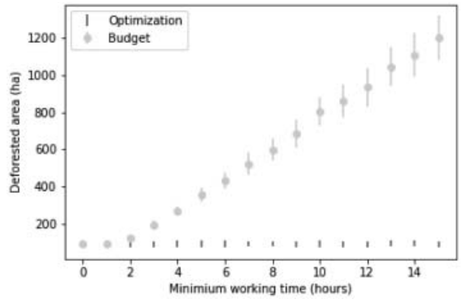
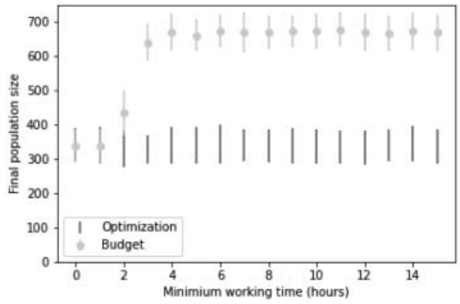
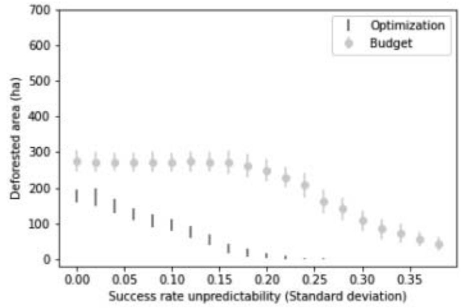
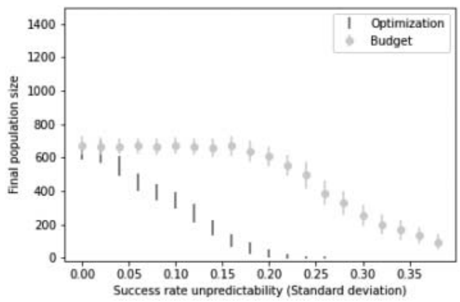
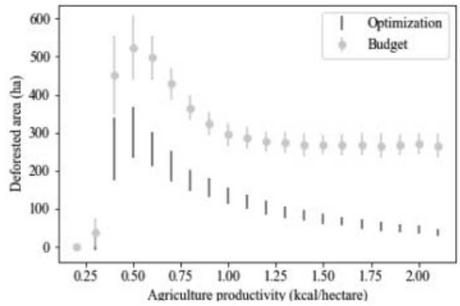
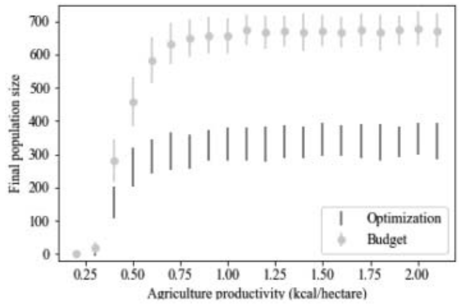
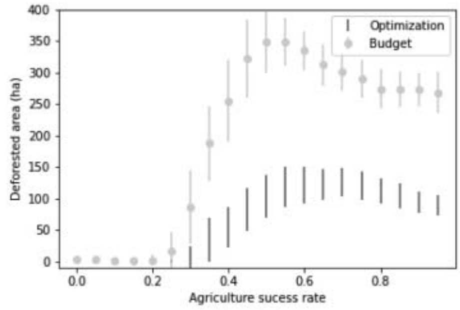
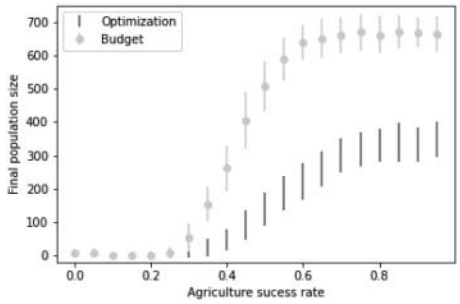
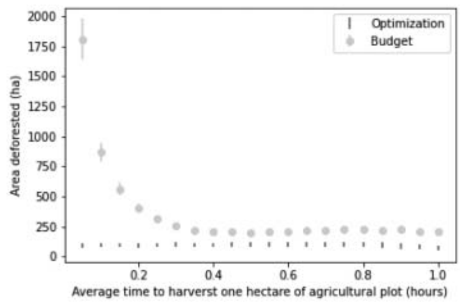
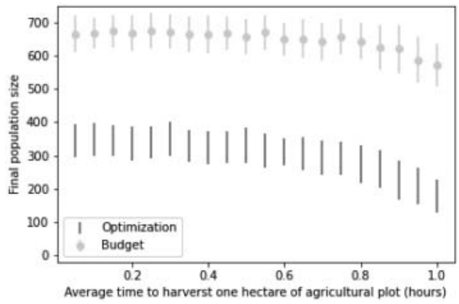
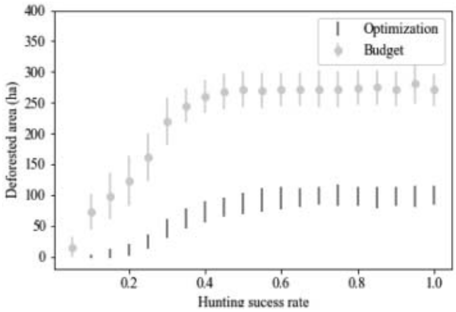
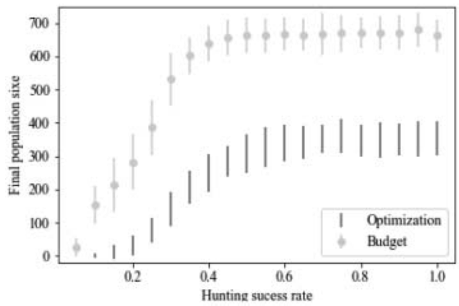
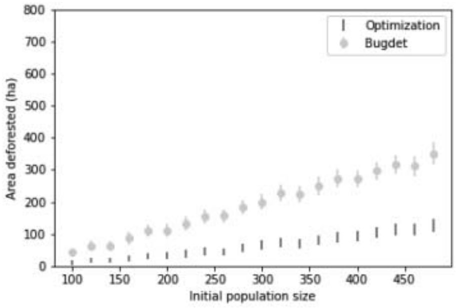
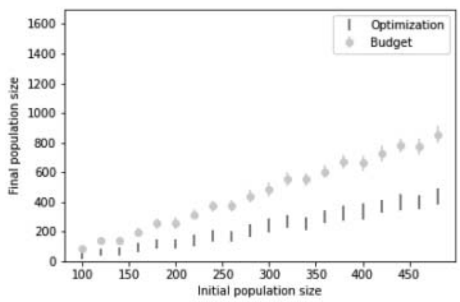
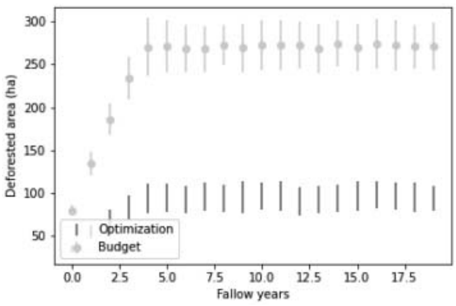
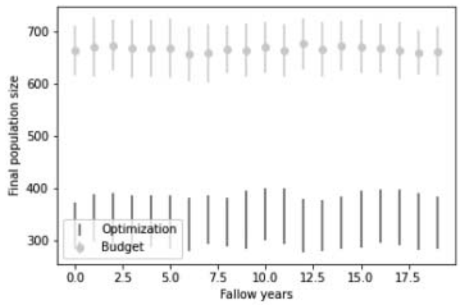
Supplement 1: Results of the sensitivity analyses.

Parameters	Area Deforested	Population Size
Minimum working time budget (B_{min})		
Success rates unpredictability (SD)		
Agriculture productivity (Q_a)		
Agriculture average success rate (A_s)		
Time to harvest one hectare of agricultural plot (T_a)		

Parameters	Area Deforested	Population Size
Hunting average success rate (H_s)		
Average initial population size		
Fallow year		

Source: Adapted from CUNHA, P.R., RODRIGUES NETO, C., MORSELLO, C. 2022. Decision-model assumptions matter: two agent-based approaches to predict deforestation among Amazonian indigenous people. *Research article in preparation.*