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Luis Enrique Escalante Ochoa

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Normandie Université

THÈSE

Pour obtenir le diplôme de doctorat

Spécialité SCIENCES ECONOMIQUES

Préparée au sein de l'Université Le Havre Normandie

**L'impact du changement climatique sur la pauvreté des femmes.
Application à la Bolivie**

**Présentée et soutenue par
LUIS ENRIQUE ESCALANTE OCHOA**

**Thèse soutenue le 20/09/2022
devant le jury composé de**

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Résumé

La Bolivie traverse actuellement une période d'opportunités sans précédent pour un changement social positif. Toutefois, ces possibilités pourraient être compromises dans un contexte de changement climatique qui s'est aggravé et intensifié au cours des dernières années. Les initiatives d'adaptation aux niveaux national, régional et même local, ainsi que le nombre croissant d'études visant à évaluer les effets du changement climatique à différentes échelles suggèrent que la Bolivie a franchi certaines étapes dans le processus de compréhension et de réponse aux effets du changement climatique. Toutefois, cela ne semble pas suffisant car le pays doit encore élaborer et mettre en œuvre des politiques adoptant des approches plus globales pour contribuer à combler les écarts entre les sexes qui persistent et sont exacerbés par le changement climatique et les catastrophes climatiques. Cette thèse apporte un éclairage sur cette question et permet d'analyser la vulnérabilité des femmes et des hommes à différents phénomènes climatiques. Tout au long de cette thèse, nous présentons trois chapitres qui utilisent des modèles d'équilibre général calculable liés à des microsimulations pour évaluer les impacts socio-économiques du changement climatique et des catastrophes climatiques.

Dans le premier chapitre, nous présentons un modèle d'EGC statique pour évaluer les impacts du changement climatique liés aux aspects à long terme. Plus précisément, nous étudions des scénarios liés à la baisse des rendements de la production agricole, à la hausse des prix internationaux et aux dommages causés au capital agricole dans un contexte de changement climatique. Ces simulations révèlent que les impacts négatifs initialement observés dans les secteurs agricoles se transmettent au reste des secteurs, affectant l'ensemble de l'économie. L'emploi est réduit et la charge de travail domestique augmente, surtout pour les femmes. De plus, la pauvreté augmente, les femmes rurales étant les plus touchées.

Dans le deuxième chapitre, nous nous concentrons sur les catastrophes climatiques et présentons une analyse ex-post des événements catastrophiques produits entre 2013-2014 sur la sécurité alimentaire des femmes et la pauvreté alimentaire. La simulation révèle des impacts négatifs sur l'économie bolivienne, en particulier sur l'agriculture des régions des highlands et des valleys. La disponibilité alimentaire est réduite, les prix des aliments augmentent et cela se traduit par une augmentation de l'insécurité alimentaire et de la pauvreté alimentaire, les ménages dirigés par des femmes étant les plus touchés.

Le troisième chapitre est une extension de l'article précédent. Un modèle dynamique y est utilisé pour analyser l'impact ex-post des catastrophes climatiques, ainsi que l'analyse des politiques de reconstruction. Les résultats révèlent que les dommages causés par les catastrophes ont des effets négatifs sur l'économie, tandis que les investissements dans la reconstruction ont des effets positifs. Cependant, il n'y a pas d'améliorations claires dans la réduction des écarts entre les inégalités de genre qui subsistent même avec la reconstruction. Ces résultats révèlent la nécessité d'intégrer une perspective de genre dans l'analyse des catastrophes climatiques et dans les politiques de prévention qui vont au-delà de la reconstruction.

Abstract

Bolivia is currently experiencing a period of unprecedented opportunities for positive social change. However, these opportunities could be compromised in a context of climate change that has worsened and intensified in recent years. Adaptation initiatives at the national, regional and even local levels, as well as the growing number of studies aimed at assessing the effects of climate change at different scales, suggest that Bolivia has taken some steps in the process of understanding and responding to the effects of climate change. However, this does not seem to be enough, as the country still needs to develop and implement policies that adopt more comprehensive approaches to help close the gender gaps that persist and are exacerbated by climate change and climate-related disasters. This thesis sheds light on this issue and provides an analysis of the vulnerability of women and men to different climatic phenomena. Throughout this thesis, we present three chapters that use computable general equilibrium models linked to microsimulations to assess the socio-economic impacts of climate change and climate-related disasters.

In the first chapter, we present a static CGE model to assess the impacts of climate change related to long-term aspects. Specifically, we study scenarios related to declining agricultural production yields, rising international prices and damage to agricultural capital in the context of climate change. These simulations reveal that the negative impacts initially observed in the agricultural sectors are spread to the rest of the sectors, affecting the whole economy. Employment is reduced and domestic workload increases, especially for women. In addition, poverty increases, with rural women being the most affected.

In the second chapter, we focus on climate-related disasters and present an ex-post analysis of the disaster events produced between 2013-2014 on women's food security and food poverty. The simulation reveals negative impacts on the Bolivian economy, particularly on agriculture in the highlands and valleys. Food availability is reduced, food prices increase and this translates into increased food insecurity and food poverty, with female-headed households being the most affected.

The third chapter is an extension of the previous article. A dynamic model is used to analyse the ex-post impact of climate disasters, as well as the analysis of reconstruction policies. The results show that damage caused by disasters has negative effects on the economy, while investments in reconstruction have positive effects. However, there are no clear improvements

in reducing the gender gaps that remain even after reconstruction. These results reveal the need to integrate a gender perspective into climate disaster analysis and prevention policies that go beyond reconstruction.

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Liste des abréviations

ADEMAF : Agence pour le développement des Macro régions et des zones frontalières

ALC : Amérique latine et Caraïbes

BAU : Scénario de référence

CEPAL : Commission économique pour l'Amérique latine

CO2 : Dioxyde de carbone

ECE : Enquête continue sur l'emploi en Bolivie

EGC Equilibre général calculable

FAO : Organisation des Nations unies pour l'alimentation et l'agriculture

FAOSTAT : Données statistiques de la FAO

GES : Gaz à effet de serre

IDH : Indice de Développement Humain

IDH-D : Indice de Développement Humain ajusté aux inégalités

INE : Institut national des statistiques de Bolivie

IPBES : Plateforme intergouvernementale scientifique et politique sur la biodiversité et les services écosystémiques

IPCC : Intergovernmental Panel on Climate Change

MPD: Ministère de la planification du développement (Ministerio de Planificación del Desarrollo)

OIT : Organisation internationale du travail

OCDE : Organisation de coopération et de développement économique

ODD : Objectifs de Développement Durable

ONU : Organisation des Nations Unies

PED : Pays en développement

PIB : Produit Intérieur Brut

PNUD : Le Programme des Nations unies pour le développement

WEF : Forum économique Mondial (World Economic Forum),

UDAPE : Unité d'analyse des politiques sociales et économiques de Bolivie

UPA : Unités de production agricole,

VIDECI : Vice-ministère de la défense civile de Bolivie

WDI : Indicateurs du développement de la banque mondiale (World Development Indicators)

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Introduction générale

Le changement climatique est l'un des plus grands défis de ce siècle du fait de ses conséquences multiples dans le monde entier (IPCC, 2022b). En effet, malgré la persistance d'un certain débat sur les causes du changement climatique (cycle naturel ou induit par l'homme) et sur leur impacts sur les économies (Sivakumar, 2005), la plupart des études récentes et actuelles fournissent des preuves accablantes de son occurrence et de ses causes humaines (Christensen et al., 2004; Field et al., 2014; IPCC, 2012, 2022b; Tol, 2018; Wilby & Harris, 2006).

Dans le contexte actuel, bien que l'environnement ait bénéficié d'un répit grâce aux mesures drastiques prises pour contrer les effets de la crise sanitaire mondiale, les effets du changement climatique sont toujours présents et préoccupants. À certains égards, les aspects positifs de la crise sanitaire relèvent des effets sur la nature qui englobent la poursuite des restrictions de la demande d'énergie dans des secteurs tels que l'industrie, l'aviation et les transports, qui ont permis de réduire sensiblement les tendances des émissions mondiales de CO₂ (Le Quéré et al., 2020). Ainsi, les restrictions sociales et économiques ont conduit à des améliorations de la qualité de l'air dans différentes parties du monde (Abdullah et al., 2020; Dantas et al., 2020; He et al., 2020; Mahato et al., 2020). Toutefois, ces changements n'étaient que temporaires, car l'arrivée d'un vaccin va entraîner un retour aux niveaux de production et potentiellement de pollution pré-pandémique (He et al., 2020; IPBES, 2020).

Les effets du changement climatique se poursuivent et restent observables dans le monde entier, comme l'indique le dernier rapport du Groupe d'experts intergouvernemental sur l'évolution du climat (IPCC, 2022b). Selon ce rapport, les avancées méthodologiques et les nouveaux ensembles de données ont permis une représentation spatiale plus complète des changements de température de surface, y compris dans l'Arctique. Ces améliorations, ainsi que d'autres, ont également permis d'augmenter d'environ 0,1°C l'estimation du changement de température à la surface du globe. De même, dans les scénarios illustratifs, à court terme (2021-2040), le niveau de réchauffement planétaire de 1,5°C risque fort d'être dépassé, même dans le scénario à faibles émissions de gaz à effet de serre (SSP1-2.6¹) (IPCC, 2022b).

¹ Le scénario SSP1-2.6 débute en 2015 avec de faibles émissions de GES, et des émissions de CO₂ diminuant jusqu'à un niveau net nul vers ou après 2050, suivi de niveaux variables d'émissions nettes négatives de CO₂. SSP1-2.6 est un scénario de l'IPCC compatible avec la limitation du réchauffement à 2°C.

Les impacts du changement climatique sont de plus en plus visibles et concernent de multiples dimensions. Ainsi, le rapport de l'IPCC indique que les impacts du changement climatique sur les écosystèmes, la biodiversité et les systèmes humains sont de plus en plus graves, interconnectés et souvent irréversibles. Par ailleurs, malgré les efforts déployés pour réduire les risques, les populations et les écosystèmes les moins aptes à faire face continuent de subir les effets du changement climatique (IPCC, 2022b). Les changements dans les régimes de précipitations, l'intensité et la fréquence des événements météorologiques extrêmes, l'augmentation du niveau moyen des mers, sont quelques-uns des résultats qui affectent tous les pays du monde (Pachauri & Reisinger, 2007). Toutefois, si la plupart des pays sont touchés par le contexte du changement climatique, l'intensité des conséquences n'est pas la même selon la situation géographique ou les caractéristiques socio-économiques propres à chaque pays. En effet, une littérature vaste et croissante suggère que les économies les plus pauvres et les groupes socio-économiques vulnérables subiront les impacts les plus sévères (Andersen et al., 2017; Dell et al., 2009; Field et al., 2014; IPCC, 2012, 2022b; Tol, 2018).

Parmi les groupes sociaux les plus vulnérables, les femmes seraient les plus touchées par le changement climatique, et ce principalement dans les pays les moins développés (Alston, 2014; Andersen et al., 2017; Denton, 2002; Eastin, 2018; Goh, 2012). Ce dernier aspect est également mis en évidence dans le dernier rapport du GIEC, qui présente un ensemble de travaux concluant que les changements induits par le climat ne sont pas ressentis de la même manière selon le sexe, le revenu, la classe sociale, l'origine ethnique, l'âge ou la capacité physique (IPCC, 2022b). Par conséquent, la vulnérabilité des groupes historiquement exclus, tels que les femmes, ou des communautés marginalisées (par exemple, les populations rurales et les ménages à faibles revenus), sont des aspects et des réalités qui doivent être pris en compte lorsque l'on étudie le changement climatique.

Les impacts climatiques les plus notables se sont historiquement manifestés dans les activités agricoles. Ceci s'explique par leur haut degré d'exposition et de dépendance aux conditions climatiques altérées, ainsi que par les répercussions biophysiques qui en découlent (Nazareth et al., 2018; G. C. Nelson et al., 2009, 2014). Ainsi, l'agriculture est considérée comme une activité économique très vulnérable à la variabilité et au changement climatiques. Selon Tubiello and Rosenzweig (2008), la hausse des températures, la modification du régime des précipitations, l'augmentation de la demande en eau et la fréquence accrue des événements extrêmes se conjuguèrent pour réduire progressivement les rendements des cultures et accroître les risques de production dans de nombreuses régions au cours des prochaines décennies.

Toutefois, les impacts liés au changement climatique varient considérablement dans le monde. D'une manière générale, la production alimentaire est susceptible de diminuer dans les régions les plus critiques (par exemple, les zones subtropicales et tropicales), tandis que l'agriculture des pays développés peut en fait en bénéficier, car la technologie est plus disponible et, le cas échéant, les mesures d'adaptation appropriées (Aliaga & Aguilar, 2009). Selon Hertel and Rosch (2010), d'ici le milieu du siècle, les rendements des cultures et des pâturages dans certaines régions tempérées pourraient bénéficier d'une légère augmentation, tandis que dans les régions semi-arides et tropicales, les rendements des cultures seront réduits. Néanmoins, la poursuite du réchauffement prévue pour la seconde partie du siècle risque de réduire le rendement des cultures dans toutes les régions (Hertel & Rosch, 2010; Tubiello & Rosenzweig, 2008). Ces effets et projections particulièrement négatifs pour le secteur agricole pourraient gravement affecter des dimensions telles que la sécurité alimentaire, qui est fondamentale pour assurer la nutrition et le bien-être des populations, car la sécurité alimentaire dépend directement de la dynamique et des changements dans le secteur agricole. Ainsi, les études axées sur la sécurité alimentaire, le changement climatique et les désastres climatiques indiquent que la mise en œuvre de politiques d'adaptation agricole devrait également inclure des politiques visant à assurer la sécurité alimentaire, en particulier dans les pays en développement où le secteur agricole est extrêmement vulnérable (Coulibaly et al., 2020 ; Pachauri, 2014 ; Sivakumar, 2005).

Par ailleurs, les impacts du changement climatique sont multiformes et ont des effets qui vont au-delà du secteur agricole et de la sécurité alimentaire. Par exemple, il existe une abondante littérature sur les effets du changement climatique sur les risques sanitaires (McMichael et al., 2003; Omoruyi & Kunle, 2012; Vardoulakis et al., 2015), les effets spécifiques sur les activités touristiques (Atzori et al., 2018; Lise & Tol, 2002), sur le secteur pétrolier et gazier (Cruz & Krausmann, 2013), entre autres. Cela montre la complexité des effets multidimensionnels du changement climatique au niveau mondial.

Les études à l'échelle régionale et mondiale sont importantes et permettent de comprendre l'étendue et l'ampleur des problèmes liés au changement climatique. Toutefois, des études spécifiques (au niveau des pays, voire des régions à l'intérieur des pays) pourraient fournir une analyse plus approfondie. C'est pourquoi la présente thèse se concentre sur le développement d'études basées sur des approches locales. Plus précisément, elle s'inscrit dans le cadre de l'étude du changement climatique en Bolivie, qui constitue le cœur géographique de l'Amérique du Sud. En effet, la Bolivie est un pays enclavé situé dans le centre-ouest de

l'Amérique du Sud avec une superficie de 1 098 581 km², soit près de deux fois la taille de la France et trente fois celle de la Belgique. Située entre l'équateur et le tropique du Capricorne, la Bolivie est un pays tropical composé de trois grandes zones géographiques : la région montagneuse des Andes ou « highlands », les vallées sub-andines, également appelées « valleys », et les plaines amazoniennes orientales, également appelées « lowlands ».

L'intérêt porté pour la Bolivie s'explique par le fait qu'elle est considérée comme le deuxième pays le plus vulnérable d'Amérique latine au changement climatique, et le huitième pays le plus vulnérable au monde (Kreft et al., 2016). Selon l'IPCC (2022), le nombre de jours supplémentaires d'exposition aux vagues de chaleur entre 2016 et 2020 par rapport à la période allant de 1986 à 2005 a augmenté de 2,2. Cette situation augmente l'intensité des impacts du changement climatique et donc la vulnérabilité de la Bolivie.

Selon l'IPCC, la vulnérabilité dans un contexte du changement climatique peut être définie comme le degré de sensibilité d'un système aux effets néfastes du changement climatique, y compris la variabilité et les extrêmes climatiques, et son incapacité à y faire face. En Bolivie, la vulnérabilité s'explique par une augmentation significative du nombre des événements naturels défavorables liés au changement climatique ainsi que de leur intensité (García del Castillo & Naranjo Mejía, 2016; Jaramillo, 2009), mais aussi en raison des ressources limitées dont elle dispose et qu'elle alloue à l'adaptation au climat.

Tableau 0.1: Type d'événements naturels indésirables signalés, 2010-2018 (en nombre d'événements)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	TOTAL
Accident	0	0	0	0	0	0	0	0	0	0
Tempête	38	17	30	29	56	56	36	45	65	372
grêle										
Froid et gel	4	3	34	5	4	11	24	21	50	156
Incendie	8	5	5	1	3	76	57	80	56	291
Inondations	87	61	123	73	100	85	47	51	172	799
Mouvement	11	10	9	9	11	27	8	11	21	117
de masse										
Neige	1	0	0	4	2	17	0	1	15	40
Pest	0	0	0	0	0	0	0	4	1	5
Sècheresse	114	15	26	88	19	40	35	28	2	367
Sismique	0	0	0	1	3	5	1	0	1	11
Tempête	7	6	5	8	13	23	10	9	14	95
vent										
Orage	0	0	3	2	12	35	13	14	21	100
TOTAL	270	117	235	220	223	375	231	264	418	2353

Source : Vice - Ministère de la défense civile (VIDECI, 2018).

Comme le montre le tableau 0.1, les effets du changement climatique au sein de la Bolivie se manifestent de différentes manières telles que : inondations, mouvements de masse, tempêtes de grêle, sécheresses, orages, incendies, etc. Selon l'Unité d'analyse de la politique économique et sociale (UDAPE), les inondations restent l'événement naturel le plus fréquent en Bolivie (UDAPE, 2015). De même, les statistiques du vice-ministère de la défense civile en Bolivie (VIDECI) pour la période 2008-2018, révèlent qu'au cours de ces années, la Bolivie a été principalement touchée par les inondations, qui ont enregistré un total de 799 (soit 40% du nombre total de phénomènes naturels indésirables). Toutefois, des occurrences fréquentes de sécheresses, de gelées et de grêles sont également enregistrées sur l'ensemble du territoire (voir tableau 0.1).

Il faut noter qu'au cours des dernières années et en particulier depuis 2015, le nombre de sécheresses a fortement diminué. Ce n'est toutefois pas le cas de l'intensité de ces épisodes, qui a au contraire été de plus en plus forte et a généré des pertes économiques importantes. En

2016, la Bolivie a subi la pire sécheresse depuis 25 ans, selon l'Organisation météorologique mondiale (OMM), qui a décrit 2016 comme l'année la plus chaude de ces dernières décennies. À tel point que le gouvernement bolivien a décrété l'état d'urgence, ce qui a entraîné le rationnement de l'eau dans tout le pays. Par ailleurs, un autre phénomène qui a enregistré une augmentation exorbitante tant en fréquence qu'en intensité est celui des incendies qui, aujourd'hui, constituent également l'un des plus grands problèmes environnementaux du pays. Bien que le nombre d'incendies augmente d'année en année en raison du changement climatique, il est également vrai qu'en Bolivie, un grand nombre d'entre eux sont causés par l'homme. Selon (Soto Quiroz, 2011), les responsables de ces incendies sont souvent des indigènes et des paysans, qui les déclenchent afin d'étendre leurs zones de culture. Il s'agit d'une technique périlleuse, connue sous le nom de "chaqueo".

Bien que les effets du changement climatique soient observables et se soient intensifiés dans toute la Bolivie, les preuves empiriques de leurs impacts, tant en termes de statistiques que de causalité, sont limitées et peu d'études analysent les implications des effets du changement climatique sur l'économie dans son ensemble. La plupart des études de ce type indiquent que le changement climatique a un impact significatif et direct sur les activités agricoles, entraînant des pertes de productivité et des pertes économiques substantielles au sein de ce secteur (Aliaga & Aguilar, 2009; Andersen et al., 2014; Jemio et al., 2014; F. E. Viscarra et al., 2018). Cela pourrait affecter davantage la sécurité alimentaire déjà fragile du pays. En effet, selon (OXFAM, 2009), la Bolivie est un pays ayant un faible niveau d'autonomie par rapport aux aliments qu'elle consomme (elle est importatrice nette d'aliments) et c'est aussi un pays dont le niveau d'approvisionnement pour les besoins alimentaires de sa population, principalement dans les zones rurales, est critique.

Par ailleurs, il existe également des dommages indirects liés aux phénomènes climatiques, et notamment des impacts dans les secteurs non-agricoles qui ont été peu explorés. Une analyse des effets directs et indirects associés aux événements météorologiques de 2013 et 2014 réalisée par l'(UDAPE, 2015) indique que les événements ont causé des pertes d'environ 3132 Millions de Bolivianos (BOB) (ou 411 millions d'euros (EUR), en appliquant la conversion BOB/EUR à 2021) et ont affecté plus de 300 000 personnes. De plus, selon l'agence pour le développement des Macro régions et des zones frontalières (ADEMAF), les zones frontalières des vallées inter-andines de Bolivie ont subi les dégâts les plus importants (ADEMAF, 2014).

Au-delà de la fréquence et de l'intensité accrues des événements climatiques, des facteurs tels que les niveaux élevés de pauvreté et d'inégalité dans différentes dimensions, explique également la forte vulnérabilité de la Bolivie au changement climatique. En effet, ces aspects conditionnent d'une certaine manière les personnes et leurs capacités d'adaptation aux changements climatiques. Bien que la Bolivie soit l'un des pays qui a le plus réduit la pauvreté entre 2005 et 2019 passant de 59,6% à 37,2% (WDI, 2019), ce taux est encore élevé en comparaison de celui des pays voisins comme l'Équateur (25%) ou le Pérou (20%) (WDI, 2019). En outre, selon l'Institut national de statistique (INE), les taux de pauvreté sont très variables au sein du pays, en raison de caractéristiques culturelles et de réalités économiques très différentes selon les régions et les groupes de population. En général, la population rurale de Bolivie présente des niveaux de pauvreté plus élevés que la population urbaine. De même, des régions telles que l'Altiplano, qui recouvre les hauts plateaux de Bolivie et compte de grandes populations rurales, concentrent les taux de pauvreté les plus élevés et sont fortement tributaires des activités agricoles (INE, 2018b). Selon Meldrum et al. (2018), les agriculteurs de cette région ont été confrontés à une augmentation des parasites et des maladies et à un déclin des cultures traditionnelles en raison des stress liés au changement climatique, aux migrations et aux facteurs d'intensification. Par ailleurs, les statistiques par sexe montrent que les femmes sont presque 2 points de pourcentage plus pauvres que les hommes (INE, 2019). De plus, chez les femmes, les différences de pauvreté sont encore plus accentuées par la zone de résidence. Ainsi, les niveaux de pauvreté des femmes rurales atteignent 52% alors qu'ils atteignent 32% dans les zones urbaines (INE, 2019).

Concernant les inégalités en Bolivie, il existe également des écarts importants à l'intérieur du pays mais aussi par rapport aux pays voisins de la région latino-américaine. Afin de classer les pays selon leur développement qualitatif et pas uniquement économique, le Programme des Nations unies pour le développement (PNUD) définit ainsi l'IDH : "L'indicateur de développement humain mesure le niveau moyen auquel se trouve un pays donné selon trois critères essentiels du développement humain : longévité, instruction et conditions de vie". Ainsi, en Amérique Latine le PNUD classe la majorité des pays de la région avec un indice de développement humain élevé, mais la Bolivie est l'un des rares pays à avoir un indice de développement humain moyen (0,693) en 2018.

En outre, selon le (PNUD, 2015), lorsque l'on ajuste l'indice en fonction des inégalités (IND-D²), le pays perd 24,2 % de progrès en matière de développement humain et sa valeur tombe à 0,533. La composante qui présente la plus grande perte due à l'ajustement pour l'inégalité est le revenu (29,7 %), ce qui signifie que malgré la croissance économique du pays, les revenus qui en découlent n'ont pas été distribués plus équitablement parmi la population.

Par ailleurs, l'indice (ou coefficient) de Gini, qui est un indicateur synthétique du niveau d'inégalité allant de 0 (égalité parfaite) à 1 (inégalité extrême), se révèle particulièrement élevé dans ce pays et montre une augmentation de deux points de pourcentage, passant de 41,6 en 2019 à 43,6 en 2020 (WDI, 2020). En outre, ce coefficient n'est pas uniforme sur l'ensemble du territoire et présente une variabilité intéressante, affectant certaines régions plus que d'autres. En général, l'indice est nettement plus élevé dans les zones rurales du pays, ce qui reflète des niveaux d'inégalité plus élevés dans les régions où la population rurale est plus importante (ECE, 2019).

Quant aux inégalités de genre, malgré les progrès réalisés, il existe toujours des écarts importants entre les hommes et les femmes et par conséquent des niveaux très élevés d'inégalité de genre. En effet, selon le PNUD (2015), l'indice d'inégalité de genre en Bolivie a atteint 0,45 alors que la moyenne de cet indice en Amérique latine est de 0,39. L'indice mondial d'inégalité entre les sexes classe la Bolivie à la onzième place parmi les 25 pays de la région Amérique latine et Caraïbes (ALC) (WEF, 2020).

Par ailleurs, les inégalités de genre ne se limitent pas aux inégalités de revenus, mais peuvent être observées dans des secteurs tel que l'éducation ou le marché du travail. Ainsi, selon le PNUD (2015), au cours de la période 2000-2015, le pourcentage de la population ayant au moins un niveau d'éducation secondaire est plus élevé chez les hommes que chez les femmes (58,7% contre 49,6%). De même, selon des données issues de l'enquête continue sur l'emploi (ECE, 2018), les femmes ont tendance à être davantage associées à des niveaux d'éducation plus faibles tandis que les hommes sont plutôt associés à des niveaux d'éducation plus élevés. Aussi, tant pour les hommes que pour les femmes, la population rurale a un niveau d'éducation inférieur à celui de la population urbaine. Le niveau d'éducation est un facteur qui facilite souvent l'accès au marché du travail, de sorte que les travailleurs les plus qualifiés trouveront plus facilement un emploi. Cela expliquerait en partie l'existence d'écarts importants entre les

² L'indice IDH-D représente l'indice de développement humain ajusté aux inégalités, et prend en compte des aspects tels que l'inégalité dans l'éducation et l'inégalité des revenus (PNUD, 2015).

sexes sur le front de l'emploi. En effet, les femmes boliviennes ont tendance à être beaucoup moins actives que les hommes sur le marché du travail. Selon la Banque mondiale, le taux d'activité des femmes boliviennes est presque 20 points de pourcentage inférieur à celui des hommes (WDI, 2020). Par ailleurs, bien que la participation des femmes à la population active en Bolivie soit supérieure à celle observée en moyenne dans la région Amérique latine et Caraïbes (ALC) (65% contre 52%) (WDI, 2020), leur activité est concentrée dans des secteurs qui, en général, contribuent moins au PIB (voir tableau 0.2). De même, les femmes boliviennes sont beaucoup plus susceptibles que les hommes d'occuper des emplois qualifiés de vulnérables par la Banque mondiale (69,7 % contre 58,7 %) (WDI, 2018).

Tableau 0.2: Production et répartition de l'emploi par genre et par secteurs agrégés, 2012 et 2019 (en %)

Secteur	PIB (%)		Emploi féminin (%)		Emploi masculin (%)		Emploi total (%)	
	2012	2018	2012	2019	2012	2019	2012	2019
Agriculture	12	13	27	28	28	28	28	28
Industrie	41	37	11	10	28	30	21	22
Services	42	50	62	62	44	42	51	50
TOTAL			100.00	100.00	100.00	100.00	100.00	100.00

Note a : Le secteur de l'industrie comprend les industries extractives, l'industrie manufacturière, la construction et les services publics (électricité, gaz et eau)

Note b : Le secteur agricole comprend les activités d'agriculture, de chasse, de sylviculture et de pêche

Note c : Les services comprennent le commerce de gros et de détail, les hôtels et restaurants, les transports, l'intermédiation financière, l'immobilier, l'administration publique, l'éducation, les soins de santé, les services sociaux, les autres services, etc.

Source : Construction propre issue des données de la banque mondiale (WDI 2012-2019)

Le tableau 0.2 illustre la contribution des secteurs économiques au PIB total ainsi que leur contribution en termes d'emploi masculin et féminin en 2012 et 2019 en regroupant les secteurs économiques en trois secteurs agrégés : l'agriculture, l'industrie et les services (WDI, 2018-2019). La contribution du secteur des services au PIB est la plus importante et affiche une augmentation significative entre 2012 and 2018. En revanche, leur contribution en termes d'emploi a décliné d'un point de pourcentage, suggérant que l'augmentation de la contribution au PIB de ce secteur n'était pas nécessairement due à la création d'un plus grand nombre d'emplois. Il faut noter toutefois que les services concentrent davantage d'emplois féminins que masculins. Quant à l'industrie, sa contribution au PIB est aussi importante. Cependant cette dernière a diminué de 4 points de pourcentage, passant de 41 % en 2012 à 37 % en 2018. De plus, l'emploi sectoriel dans l'industrie enregistre une augmentation d'un point de pourcentage

sur la même période et il faut noter que l'industrie est un secteur fortement intensif en termes de main d'œuvre masculine (plus de 30% de l'emploi masculin total contre 10% chez les femmes). Enfin, nous avons la contribution du secteur agricole au PIB, qui est la plus faible et qui n'a augmenté que d'un point de pourcentage, passant de 12 % en 2012 à 13 % en 2018. Ce secteur concentre 28% de l'emploi total. De plus, entre 2012 et 2019, l'emploi féminin y a augmenté d'un point de pourcentage alors que l'emploi masculin est resté constant.

Une caractéristique importante de l'économie bolivienne est le degré élevé d'informalité sur le marché du travail. Il s'agit d'un ensemble d'activités qui sont sous-estimées par les comptes nationaux parce qu'elles se déroulent dans des circonstances non contrôlables et non réglementées. Selon l'Organisation internationale du travail (OIT), la proportion d'emplois informels en Bolivie est la plus élevée d'Amérique du Sud, atteignant 84,9 % en 2019 (ILOSTAT, 2021). L'un des secteurs les plus liés à l'informalité est celui du commerce. De fait, selon le rapport de l'OIT intitulé "Perspectives sociales et de l'emploi dans le monde", plus de 90 % de l'emploi des travailleurs du secteur du commerce en Bolivie est informel (ILO, 2019). Il convient également de noter que ce secteur en particulier présente une forte participation des femmes. Cela révèle une fois de plus l'existence des inégalités de genre au sein du marché du travail. Selon les Nations unies (ONU), 70 % des Boliviennes travaillent de manière informelle et un bon pourcentage de celles qui sont en règle gagnent 50 % de moins que les hommes. (ONU Mujeres, 2020).

Sur le marché formel, les femmes boliviennes travaillent dans un éventail restreint de secteurs et sont souvent moins bien payées que les hommes. L'hébergement et les services de restauration, l'éducation, la santé et les services sociaux, ainsi que les activités ménagères privées sont les secteurs à plus forte intensité de main-d'œuvre féminine (INE, 2018b) et sont souvent associés à de faibles salaires. À ces secteurs s'ajoute le secteur agricole qui, bien que n'étant pas à forte intensité féminine, représente un peu plus de 30 % de l'emploi féminin total (WDI, 2020). Dans les zones rurales du pays, l'agriculture est la principale activité des femmes. Cependant, elle est associée à des salaires et des niveaux de productivité extrêmement bas, dans la mesure où il s'agit d'une agriculture de subsistance. Selon le recensement agricole de 2013, plus de 50 % des unités de production agricole (UPA), représentant près d'un tiers de la population bolivienne, pratiquent une économie de subsistance. Ce type d'économie constitue un système économique de la société préindustrielle, basé sur une agriculture de subsistance, avec des exploitations agricoles, généralement familiales, dont le seul objectif est de se nourrir. En Bolivie, l'agriculture de subsistance est fortement liée à une agriculture à faible productivité

et à une disponibilité limitée de terres productives (INE, 2013). Ces tendances sur le marché du travail montrent non seulement que la participation des femmes au marché du travail bolivien est systématiquement inférieure à celle des hommes dans la plupart de secteurs, mais aussi que leur activité est systématiquement moins valorisée économiquement.

Tableau 0.3: Répartition sectorielle de l'emploi en Bolivie selon genre, 2017 (en %)

	Emploi Hommes (%)	Emploi Femmes (%)	Intensité des femmes (%)
Agriculture, élevage, chasse, pêche et sylviculture	20,36	19,30	45
Industrie minière	2,83	0,29	8
Industrie manufacturière	12,08	10,75	43
Fourniture d'électricité, gaz et vapeur	0,32	0,07	16
Approvisionnement et gestion des déchets	0,25	0,06	17
Construction	15,66	0,62	3
Commerce de gros et de détail, réparation automobile	13,72	27,59	63
Transport et stockage	12,73	0,83	5
Activités d'hébergement et de restauration	3,11	14,13	79
Information et communication	1,09	0,56	30
Intermédiation financière et assurance	0,66	0,91	54
Activités immobilières	0,31	0,62	62
Services professionnels et techniques	2,12	1,62	39
Activités des services administratifs et de soutien	1,51	1,80	50
Administration publique, défense et sécurité sociale	4,14	2,78	36
Services d'éducation	3,74	6,74	61
Santé et services sociaux	1,51	4,23	70
Activités artistiques, de divertissement et de loisirs	1,23	0,39	21
Autres activités de services	2,40	2,87	50
Activités des ménages privés (tâches domestiques)	0,18	3,86	95
Service des organismes extraterritoriaux	0,02	0,00	0
TOTAL	100	100	

Note : l'intensité des femmes est définie comme le pourcentage de la main-d'œuvre féminine dans un secteur spécifique. Une proportion supérieure à 50 % indique que le secteur est à forte intensité féminine

Source : Construction propre issue des données l'enquête continue sur l'emploi (ECE, 2017)

Le tableau 0.3, montre la répartition sectorielle de la main-d'œuvre bolivienne par sexe à partir de l'enquête continue sur l'emploi (ECE, 2017). Dans la dernière colonne, nous pouvons voir le degré d'intensité de chaque secteur en matière de travail féminin, et seuls 7 des 21 secteurs enregistrés dans la ECE sont intensifs en main-d'œuvre féminine. Qui plus est, certains

de ces secteurs sont de faible productivité. C'est le cas des activités d'hébergement et de restauration, santé et services sociaux, et des tâches domestiques, dans lesquelles l'intensité de la main-d'œuvre féminine dépasse 70%. De même, la participation des femmes au marché du travail est principalement concentrée dans trois secteurs économiques : l'agriculture et dérivés, le commerce de gros et de détail, et les activités d'hébergement et de restauration. Quant à la main-d'œuvre masculine, elle est principalement concentrée dans les secteurs agriculture et dérivés, l'industrie manufacturière, le transport et la construction.

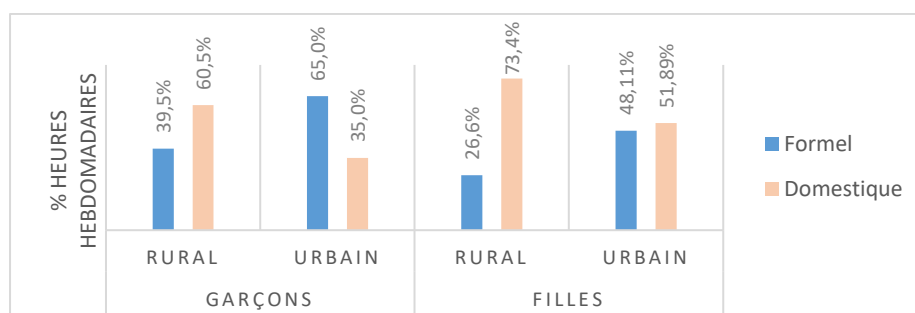
Les inégalités entre les hommes et les femmes sur le marché du travail ressortent encore davantage si l'on tient compte du fait que les individus consacrent également du temps à des activités non rémunérées dans la sphère non commerciale de l'économie, et plus particulièrement au travail domestique non rémunéré. Becker (1965) développe pour la première fois la notion de travail domestique dans les années 1960. Auparavant, ces tâches n'étaient considérées ni comme un travail ni comme un loisir. La convention (n° 189 de l'OIT) définit le « travail domestique » effectué par un travailleur ou une travailleuse domestique au sein d'un ou plusieurs ménages dans le cadre d'une relation de travail. Toutefois, la notion de travail domestique a progressivement été élargie pour permettre d'englober les travaux non rémunérés réalisés dans la sphère domestique, devenant ainsi outil d'analyse des inégalités entre les hommes et les femmes. Selon l'OCDE (2011), le travail non rémunéré constitue la part de travail domestique qui augmente indirectement les revenus du foyer, sans que les personnes qui l'effectuent ne bénéficient de rémunération. Le ménage, la garde des enfants, la préparation des repas, la lessive, l'approvisionnement en eau et en carburant sont aujourd'hui des exemples de travail domestique.

Quant à la mesure et à la quantification de la contribution du travail domestique, elle repose sur des enquêtes sur l'emploi du temps propres à chaque pays. Cela rend parfois difficile une définition commune des activités qui englobent le travail domestique. En plus, comme ces activités se font principalement dans la sphère privée (le ménage) et qu'il s'agit d'une production non commerciale, il est difficile d'en faire une mesure précise (Ferrant et al., 2014). En Bolivie, étant donné l'absence d'enquêtes continues sur l'emploi du temps au niveau national et le manque de fiabilité des informations disponibles, il existe peu d'études et de rapports sur la contribution réelle du travail domestique. Toutefois, des études basées sur des enquêtes pilotes³ sur l'emploi du temps indiquent que les activités non rémunérées en Bolivie sont essentiellement

³ L'enquête pilote est une stratégie qui permet d'évaluer ou de tester un questionnaire en utilisant un échantillon de taille plus réduite que l'échantillon prévu.

centrées sur le travail domestique et les activités de soins, le travail domestique étant la principale activité (Canelas & Salazar, 2014; CEPAL, 2001; Medeiros et al., 2010). De même, la charge domestique pèse davantage sur les femmes boliviennes par rapport aux hommes et ceci est conforme à la tendance rapportée par (Rubiano-Matulevich & Viollaz, 2019), pour la plupart des pays en développement (PED), où l'on constate que le travail domestique est principalement effectué par les femmes. En outre, en Bolivie, la charge du travail domestique affecte particulièrement les femmes vivant dans les zones rurales, ce qui les rendrait encore plus vulnérables et les éloignerait du marché formel générateur de revenus (Ashwill et al., 2011). Ces tendances qui font état d'une forte présence des femmes boliviennes dans les tâches domestiques ont en partie une explication culturelle, puisque les tâches domestiques incombent principalement aux femmes depuis qu'elles sont enfants. A cet égard, Zapata et al., (2011) analysent le travail domestique effectué par les enfants boliviens, et indiquent que le travail domestique des enfants se caractérise par l'emploi de filles dans une plus grande proportion que les garçons. Selon les auteurs, les filles ont 23 % plus de chances que les garçons de ne pas aller à l'école et de travailler lorsque la définition inclut les tâches domestiques, et cette probabilité augmente à mesure que le travail s'intensifie pendant les heures de travail domestique.

Figure 0.1: Part d'heures hebdomadaires consacré au travail domestique et au travail formel des enfants selon le genre en Bolivie, 2016 (en %)



Source : Construction propre issue des données l'enquête auprès des enfants qui travaillent en Bolivie (ENNA, 2016)

La figure 0.1 présente les données issues de l'enquête sur les enfants qui travaillent en Bolivie (ENNA, 2016). Les niveaux les plus élevés de travail domestique se trouvent dans le secteur rural, où les filles ont également une plus grande participation que les garçons (73,4% contre 60,5%) ; tandis que dans le secteur urbain, le travail formel occupe la place la plus importante avec une plus grande participation des garçons que des filles (65% contre 48,11%). De même, tant dans les zones rurales qu'urbaines, la proportion d'heures consacrées au travail domestique est plus élevée chez les filles que chez les garçons.

Les inégalités entre les sexes dans des dimensions telles que l'éducation et la pauvreté, et principalement sur le marché du travail (tant dans la sphère commerciale que non commerciale), soulignent l'existence de fortes disparités entre les sexes en Bolivie, ainsi que la présence de groupes vulnérables (population rurale, femmes, entre autres). Toutefois, bien que les preuves en Bolivie indiquent que ces disparités sont marquées, des aspects tels que la dimension de genre ou la prise en compte de groupes vulnérables spécifiques ont été particulièrement absents tant des études socio-économiques que des politiques économiques.

En ce qui concerne les études d'évaluation d'impact et de modélisation liées au changement climatique ou aux catastrophes climatiques, la plupart des études adoptent des approches neutres en termes de genre, considérant que les hommes et les femmes sont touchés de la même manière. Cependant, les récents rapports de l'IPCC, ainsi que différentes études appliquées principalement aux pays en développement, suggèrent que ces impacts ne sont pas neutres et affectent différemment les hommes et les femmes (Alston, 2014; Demetriades & Esplen, 2010; Denton, 2002; Eastin, 2018; Goh, 2012; IPCC, 2022a)

Dans le cas spécifique de la Bolivie, les écarts de genre ainsi que les écarts régionaux et géographiques montrent un net désavantage et une plus grande vulnérabilité des femmes, principalement dans les zones rurales, où elles dépendent de l'agriculture pour leur subsistance, doivent faire face à des charges domestiques plus lourdes et ont tendance à s'enliser dans la pauvreté. En tenant compte des écarts entre les hommes et les femmes à la fois dans les sphères commerciales et non commerciales de l'économie bolivienne, cette thèse propose d'analyser les différents impacts socio-économiques du changement climatique et des catastrophes climatiques dans une perspective de genre, où nous nous intéresserons particulièrement aux effets sur le bien-être des femmes boliviennes. Quel est l'impact du changement climatique et des catastrophes climatiques sur les activités agricoles et non agricoles en Bolivie ? ces impacts sont-ils différents pour les hommes et les femmes ? quels sont les liens entre les catastrophes climatiques, le genre et la sécurité alimentaire ? Quelles politiques faut-il adopter pour réduire la vulnérabilité au changement climatique ? Ce sont les principales questions de recherche auxquelles nous répondrons tout au long de ce travail.

Il existe différentes méthodes et approches pour évaluer les questions liées aux effets du changement climatique. De manière générale, on peut distinguer deux types d'analyse. D'une part, les analyses à visée microéconomique, souvent associées à des techniques économétriques et réalisées à petite échelle, et d'autre part, les analyses à visée macroéconomique, qui analysent l'économie dans son ensemble et fournissent une analyse plus large. Pour répondre aux

questions de recherche mentionnées dans le paragraphe précédent, cette étude utilise un cadre d'équilibre général calculable (EGC). Ce dernier est un cadre d'analyse macroéconomique qui permet de reproduire les effets des chocs économiques sur les différents marchés d'une économie. Compte tenu du fait que les impacts liés aux perturbations climatiques et au changement climatique en général ont des effets directs et indirects, ce cadre de modélisation est pertinent car il permettra de saisir les effets de premier et de deuxième ordre qui sont générés dans l'ensemble de l'économie lorsque des perturbations climatiques se produisent. Ainsi, en utilisant ces modèles, il sera possible d'évaluer les effets sur la production, la demande de facteurs et les agents économiques.

Cependant, si ce cadre de modélisation permet d'avoir une vision des impacts sur l'ensemble de l'économie, l'analyse au niveau des agents économiques est très agrégée, principalement au niveau des ménages qui sont toujours des catégories représentatives. Pour remédier à ce problème, nous présentons un modèle Macro-micro, qui combine le modèle EGC avec un module de micro-simulation suivant une approche top-down. Les premières études dans le cadre de modèles d'EGC top-down ont consisté à introduire un grand nombre de ménages directement dans le modèle EGC. (Cockburn, 2004; Cogneau & Robilliard, 2007; Decaluwé et al., 1999). Cependant, cette méthode pose des problèmes en termes de résolution (Rutherford et al., 2005). (Chen & Ravallion, 2004), proposent une résolution séquentielle pour l'utilisation de ces modèles. Avec cette approche, les résultats obtenus en termes de variations de certaines variables économiques (prix, salaires, consommation, entre autres) aux niveaux, sont utilisés pour fournir les données requises par le module de micro-simulation qui vise à réaliser une analyse plus approfondie de la pauvreté et des inégalités.

Dans ce travail, nous avons choisi d'utiliser la résolution séquentielle dans notre modèle qui propose une résolution en deux étapes. Premièrement, nous construisons des modèles EGC sensibles au genre. Ce modèle permet de capter, dans un cadre d'équilibre général, les effets directs et indirects de divers chocs climatiques sur l'offre et la demande et sur les hommes et les femmes. Quant à l'inclusion de la dimension de genre dans les études EGC liées au changement climatique, elle a été particulièrement absente, car la plupart des études considèrent des approches neutres en termes de genre. Cependant, si nous élargissons la littérature aux études macroéconomiques en général, l'incorporation du genre n'est pas une nouveauté dans la littérature de modélisation EGC. La plupart des études EGC ont inclus cette dimension sur le marché du travail en désagrégeant la main-d'œuvre non seulement par sexe mais aussi par compétences (Arndt et al., 2011; Chitiga et al., 2019; Filipinski et al., 2011; Latorre, 2016a).

Un deuxième groupe d'études EGC se concentre sur la désagrégation des comptes des ménages en tenant compte d'aspects tels que le sexe du chef de ménage, le lieu de résidence, les groupes de population raciaux ou encore les quintiles de revenus (Cockburn et al., 2007; Escalante et al., 2021; Siddiqui, 2009).

Un troisième groupe d'études EGC se concentre sur l'introduction d'une perspective de genre prenant en compte la sphère non marchande. Ce cadre de modélisation a été initié par Fontana et Wood (2000) ; ces derniers proposent l'extension d'une Matrice de comptabilité sociale (MCS) genrée au Bangladesh, intégrant le travail domestique et les loisirs comme nouveaux secteurs. Ce cadre a été étendu à différents pays et, en particulier, à l'analyse des politiques économiques et commerciales (Cockburn et al., 2007; Fofana et al., 2003; Fontana, 2004; Siddiqui, 2009).

Dans le modèle EGC présenté dans cette étude, la dimension de genre incorpore une ventilation par sexe au niveau des ménages. Nous considérons également les différences entre les hommes et les femmes sur le marché du travail en fonction des différents niveaux de qualification. Enfin, nous introduisons une approche genrée en intégrant l'économie non marchande et en particulier la production des ménages. Cette approche intégrale du genre développée dans notre modèle EGC nous permet d'analyser l'impact socioéconomique des chocs climatiques, et particulièrement sur le bien-être des hommes et des femmes, tout en considérant les impacts sur l'économie marchande et non marchande. Cependant, cette approche reste au niveau agrégé. C'est pourquoi nous avons recours à la deuxième étape de la résolution séquentielle de notre modèle, qui consiste à mettre en œuvre le module de micro simulation couplé au modèle EGC macroéconomique.

L'intérêt de recourir à cette deuxième étape de la résolution séquentielle réside dans le fait que l'un des objectifs centraux de cette étude est d'analyser les impacts redistributifs sur la pauvreté monétaire, les inégalités et la sécurité alimentaire que le changement climatique pourrait engendrer. Par conséquent, la mise en œuvre de ce module permettra une analyse plus approfondie et plus riche du bien-être des ménages boliviens, car au lieu de nous limiter aux ménages représentatifs, nous recourrons à l'enquête nationale sur les ménages comme principale source de données. Cette deuxième étape, consiste en l'implémentation du module de micro-simulation qui est couplé au modèle EGC macroéconomique (approche top-down). D'un point de vue technique, nous utilisons les résultats du modèle d'EGC dans le module micro, qui comprend également un volet sur le genre, afin d'étendre l'analyse distributive sur les ménages. Le recours à une approche top-down à partir du modèle EGC nous permettra donc

d'effectuer une analyse distributive des effets de ces scénarios climatiques sur la pauvreté des individus et notamment des femmes boliviennes. Cette technique est appliquée tout au long des trois chapitres de cette thèse, qui sont brièvement décrits ci-dessous.

Le premier chapitre présente un modèle d'EGC statique sensible au genre pour évaluer les effets du changement climatique en Bolivie. Compte tenu de l'importance du secteur agricole en Bolivie, qui représente environ 30% de l'emploi total et un degré élevé d'exposition et de vulnérabilité dans un contexte du changement climatique, les scénarios étudiés dans ce chapitre se concentrent particulièrement sur le secteur agricole et nous nous intéressons donc à la dynamique de genre dans ce secteur. De même, le modèle présenté dans ce chapitre vise à améliorer la compréhension des relations entre le changement climatique, le genre et les activités non rémunérées en intégrant explicitement la charge de travail domestique non rémunérée des ménages boliviens dans le cadre de la modélisation EGC dans une perspective de genre. Deux scénarios sont évalués. Le premier scénario porte sur les dommages causés au capital et aux terres, tandis que le second analyse la diminution des rendements de la production agricole. L'analyse de la pauvreté monétaire se fait en calculant les indices de pauvreté Foster-Greer-Thorbecke (FGT) portant sur l'incidence de pauvreté (FGT0), leur profondeur (FGT1), et la sévérité de la pauvreté (FGT2). Les résultats montrent que les effets des dommages climatiques sur le capital agricole aggravent la pauvreté et les inégalités entre les sexes en Bolivie dans une plus large mesure que dans le scénario de baisse de la productivité agricole. Les impacts négatifs initialement subis par les secteurs agricoles se répercutent sur le reste des secteurs, affectant le PIB et la dynamique macroéconomique (emploi, consommation des investissements, etc.). En outre, les effets les plus négatifs seraient subis par les ménages ruraux, en particulier ceux dirigés par des femmes, car ce sont eux qui subissent les plus fortes baisses de la consommation réelle, les plus fortes augmentations des travaux domestiques et les plus fortes augmentations de la pauvreté. Ces résultats révèlent que les disparités de genre préexistantes en Bolivie sont encore renforcées dans le contexte du changement climatique, rendant les femmes boliviennes plus vulnérables que les hommes.

Le deuxième chapitre porte sur la modélisation des catastrophes climatiques en Bolivie. Étant donné la diversité du paysage bolivien, notamment en ce qui concerne l'agriculture, et contrairement au modèle précédent, nous incluons cette fois-ci des dommages régionaux spécifiques dans les différents secteurs agricoles. Ceci est pertinent en raison de la variabilité des régions en termes d'exposition et de vulnérabilité aux événements climatiques défavorables. Par conséquent, trois zones géographiques principales sont considérées sur l'ensemble du

territoire (highlands, valleys et lowlands). En outre, nous étendons l'analyse aux secteurs non agricoles qui sont également touchés par les catastrophes climatiques, et nous incluons l'analyse de la sécurité alimentaire, car nous considérons que celle-ci pourrait être affectée par l'occurrence de catastrophes climatiques. À cette fin, et comme dans le chapitre précédent, nous utilisons un modèle d'EGC statique sensible au genre couple à un module de micro-simulation, qui nous permet d'évaluer l'impact des catastrophes climatiques sur la sécurité alimentaire et la pauvreté alimentaire des femmes. Le scénario climatique est basé sur une étude des dommages subis par les secteurs agricoles et non agricoles en Bolivie en raison d'événements climatiques défavorables entre 2013 et 2014. Les résultats révèlent des impacts négatifs sur l'économie, le secteur agricole étant le plus touché et les effets s'étendant à de nombreux secteurs non agricoles. Cela affecte finalement la sécurité alimentaire, principalement la production et la disponibilité des cultures traditionnelles qui subissent les plus grandes pertes. Les résultats indiquent une réduction de la disponibilité des aliments sur le territoire local, une augmentation des prix des aliments de base, des effets négatifs sur la capacité économique des ménages à accéder aux aliments, et finalement une augmentation de la pauvreté alimentaire, principalement au sein des ménages dirigés par des femmes. Par ailleurs, tout comme dans le chapitre précédent, les résultats révèlent également des effets négatifs sur l'emploi et une augmentation des charges des ménages, qui augmentent principalement pour les femmes, les femmes des highlands étant les plus touchées, ce qui accroît leur vulnérabilité. Les ménages sont donc une fois de plus les grands perdants de notre scénario climatique, notamment ceux dirigés par des femmes, en raison de leur forte présence dans les activités agricoles traditionnelles, qui souffrent le plus des dommages climatiques. Ces résultats révèlent qu'il existe des preuves solides que les catastrophes climatiques compromettent la sécurité alimentaire de la Bolivie et affectent différemment les hommes et les femmes, en fonction de leur situation régionale.

Enfin, le troisième et dernier chapitre de cette thèse est une extension du deuxième avec deux contributions majeures. Premièrement, le modèle utilisé est un modèle d'équilibre général calculable dynamique récursif. Cela permettra d'analyser les effets des catastrophes climatiques à court et à long terme. Deuxièmement, le modèle développé dans ce chapitre constitue un cadre analytique pour simuler les politiques économiques qui peuvent être entreprises dans le cadre de l'adaptation au changement climatique et de la réduction de la vulnérabilité en Bolivie. Les modèles traditionnels axés sur l'évaluation du changement climatique et les politiques d'adaptation ont longtemps été considérés comme neutres du point de vue du genre, ce qui

comporte sans aucun doute d'importants biais liés au genre. Ce chapitre vise à apporter une contribution en simulant l'efficacité des politiques d'investissement qui permettent de réduire les effets négatifs du changement tout en favorisant une plus grande égalité entre les hommes et les femmes en Bolivie.

Les trois chapitres décrits ci-dessus constituent la production de trois articles scientifiques qui seront présentés dans les sections suivantes. La rédaction de ces articles s'est faite en anglais par volonté de s'adresser à une communauté scientifique internationale, mais aussi d'étendre nos recherches à des publications dans des revues de renommée internationale.

Chapitre 1

I. Assessing the impacts of climate change on women's poverty: A Bolivian case study⁴

Abstract: Climate change affects men and women differently, and pre-existing gender disparities may worsen. We use a gendered computable general equilibrium model linked with microsimulations to assess the distributive effects of climate change in Bolivia. Two scenarios are evaluated. The first scenario addresses capital and land damages, while the second analyses the decrease in agricultural production yields. We find that both scenarios have negative impacts on the Bolivian economy. The scenarios drive down employment and increase the burden of domestic work, especially for women. Furthermore, both simulations reveal negative impacts on poverty, with women in rural areas being the most affected.

Keywords: Climate change; Gender; Domestic work; Poverty; Bolivia; Computable General Equilibrium model

JEL: C68, J16, Q54

⁴ This article is currently undergoing minor revisions in the Journal of International Development.

1.1.Introduction

Climate change is one of the greatest challenges facing each country today. While all countries will be affected, poor countries will be affected more severely (IPCC 2014, Dell 2009, Tol 2018). Within these countries, the most vulnerable populations are the most affected (Björnberg & Hansson, 2013; Denton, 2002; Goh, 2012; Quisumbing et al., 2018). Indeed, vulnerable social groups, such as women, are the most affected by climate change not only because they are more dependent on natural resources but also because they lack the capacity to adapt to climate change (Denton, 2002). Although the impacts of climate change on economic growth are well documented, little is known about the exact consequences for women.

Bolivia is considered one of the countries most affected by extreme weather events. In 2014, it was ranked eighth among the countries most affected by extreme climatic events, while in 2013, the country was ranked 33rd (Kreft et al., 2016). The agricultural sector was particularly affected by floods and droughts in the period 2013-2014. Given the importance of the agricultural sector in total employment (30% of the population (ILOSTAT, 2019)), climatic events have resulted in income losses for rural populations. Indeed, the fact that floods and droughts are common at different times of the year in rural regions, such as the altiplano, combined with the poor quality of existing infrastructure in rural areas (irrigation, water storage), makes these areas more vulnerable to the effects of climate change (Ashwill et al., 2011). Thus, women living in rural areas are significantly poorer than their urban counterparts (52% vs. 32%, (INE, 2019)), as they have limited access to the labour market and devote a great share of their time to domestic chores (Ashwill et al., 2011; Rubiano-Matulevich and Viollaz, 2019). Given the expected impacts of climate change, water and wood might become scarcer and less accessible. Therefore, women will need more time to collect them, reducing the available time they could look for a paid activity (Demetriades & Esplen, 2010).

In this paper, we investigate the economic impact of climate change on Bolivian women and specifically on women living in rural areas. Indeed, although Bolivia is considered a country highly vulnerable to climate change, only a few studies assess the impact of climate change on the economy (Andersen et al. (2014) Aliaga and Aguilar, 2009; Jemio et al., 2014; Viscarra et al., 2018), and none of them analyse the impacts of climate change on vulnerable groups. Actually, in the literature, studies that consider vulnerable groups and especially women are micro studies and therefore cannot capture the different impacts of climate change on the

whole economy. Indeed, gender-focused macroeconomic studies that provide comprehensive analyses of climate change in specific economies are scarce. For instance, Chitiga *et al.* (2019) evaluate the impacts of climate change on South African women and find that unemployment amongst women increases more than that amongst men in the long term. However, their study focuses on the market economy, and they omit the domestic market. Indeed, women are likely to suffer more from the effects of climate change given the resulting increase in domestic chores.

This study presents a macro-micro model to analyse the effects of climate change on poverty and domestic work from a gender perspective. Specifically, we analyse whether climate change affects men and women differently in the labour market and in domestic chores. We also analyse whether climate change worsens existing differences between men and women on one side and rural and urban areas on the other side. To this end, we develop a gender-sensitive computable general equilibrium (CGE) model that is linked to a microsimulation module. CGE models are prime candidates in regard to representing links between the different sectors of the economy and the agents (households) in a consistent macroeconomic framework. Linking the CGE model to a microsimulation model allows us to evaluate the distributional impacts of climate change. The contribution of this paper is threefold. First, it presents an economy-wide analysis of climate change impacts on women in Bolivia as a case study of a climate-sensitive developing country. Second, it addresses an important issue that has received too little attention in the literature, as most of the climate change-related papers focus on economic impact and overlook the impacts on vulnerable groups, especially women. Third, the model explicitly considers the domestic market for men and women, which is a dimension neglected in the literature thus far. By showing that the effects of climate change are different for men and women, it allows for more appropriate policy recommendations to support the most vulnerable.

The remainder of the paper is organised as follows. The next section discusses the methodological framework and data. Section 3 presents the scenarios and results, while Section 4 provides a sensitivity analysis for key parameters of the model. Finally, the fifth section provides conclusions and suggests some avenues for future research.

1.2. Model and data

1.2.1. CGE Model

To evaluate the impacts of climate change on women's poverty, we use the static Partnership for Economic Policy (PEP 1-1) standard model by Decaluwé et al. 2013. However, to better represent the Bolivian features, the standard model has been modified in many ways, as presented below⁵.

In line with the social accounting matrix (SAM), the model has 20 activities and commodities. The production function technology presupposes constant returns to scale presented in a four-level production process. At the first level, production is a Leontief type of function of value added and intermediate consumption. At the second level, a CES function is used to represent the substitution between composite labour and composite capital. At the third level, composite labour is further disaggregated by skills (skilled and unskilled workers) following a CES type of function, while composite capital is a CES function of capital and land for agricultural sectors only. At the fourth level and for each skill category, the labour demand is a CES function between male and female workers. To reflect the fact that men and women are not easily substitutable, we use low elasticity of substitution values as in Fontana and Wood (2000) and Fofana et al. (2003). These values are set at 0.5 and 0.7 for skilled and unskilled workers.

The model distinguishes four different institutions: households, firms, the government and the rest of the world. Households are also disaggregated by gender and location: male-headed households in rural and urban areas and female-headed households in rural and urban areas. These households have three different sources of income: labour, capital and transfers from other agents. The income of male-headed households comes mainly from labour in both rural (89%) and urban (84%) areas. In female-headed households, income from labour is also the main source of revenue but to a lesser extent than that of male-headed households. Transfers also constitute an important part of household income, mainly in female-headed households where transfers account for 22% and 23% of income in both rural and urban areas, respectively, while in male-headed households, transfers account for only 10% and 13% of income in rural and urban areas, respectively. Finally, households receive income from capital and land. Although this source accounts for the smallest share of total income, it should be noted that

⁵ A full description of all equations, variables and sets of the CGE model can be found in the Appendix A.1

urban households receive the largest share: more than 90% of this income is earned by urban households.

All categories of households use their income for tax payments, savings, and mainly for consumption, which is specified with a linear expenditure system (LES) type of function (Stone, 1954). Finally, savings account for between 8% and 13% of total household income, with urban households making the most (12.4% in male-headed households, 12.7% in female-headed households).

Firms' income is based on transfers from other institutions and mainly on capital income. They pay income taxes and dividends, and the remaining income constitutes firms' savings. The government collects direct taxes from households and firms and indirect taxes (import duties, taxes on commodities and taxes on production) and receives transfers from other agents. These resources are used for public expenditure (mainly on nontradable commodities) and for the payment of transfers to nongovernmental agents. The remainder constitutes savings.

Bolivian workers allocate a significant part of their time to domestic activities, which prevents them from earning money. Indeed, women devote 23.5% of their daily 24 hours to doing unpaid household and care work, while men devote only 12.6% of their time to this work (CEPAL, 2001). In rural areas, the difference is even more striking, with women spending 7 hours per day on domestic chores compared to 1.4 hours for men (Ashwill et al., 2011). To complete the allocation estimates on the use of time and given the absence of disaggregated data per level of qualification in Bolivia, we used the Colombian time allocation estimates from Rubiano-Matulevich and Viollaz (2019). Based on these studies, Bolivian unskilled women allocate 5.47 hours per day for domestic work, while skilled women allocate 4.1 hours per day. Unskilled men allocate 1.25 hours per day for domestic chores and skilled men allocate 1.23 hours.

Most CGE studies concerned with modelling in the non-market sphere propose the extension of gender SAMs to include domestic work and leisure as new sectors (Cockburn et al., 2007; Fontana, 2004; Fontana & Wood, 2000; Siddiqui, 2009). However, given the lack of information to correctly introduce Bolivia's non-market sectors into the SAM, we use an alternative modelling framework that relies on the introduction of explicit labour supply functions determined by households (Fofana et al., 2003, 2005; Terra et al., 2009). Moreover, as in Terra et al. 2009, we include differences by skill level in the CGE model, in addition to the gender differences integrated in Fofana et al., (2003, 2005).

Technically and based on Fofana et al. (2003), we consider that households have a fixed amount of time (measured in hours) that they can allocate between paid work in the market sphere, leisure, and the production of a nonmarket commodity (taking care of the kids, fetching water, etc.). Therefore, households maximise their utility under the constraint of their full income, which is the sum of the different incomes from both the market sphere of the economy (labour income, land income, transfers from other agents, etc.) and the non-market spheres (home production).

Then, the time devoted to the non-market sphere creates a new commodity called “home-produced commodities”, which is made up only by labour and fully consumed by households. Moreover, the value of these commodities is equal to the value of the labour used in their production, where nonmarket labour is priced at its opportunity cost, as measured by the market wage rates. The production function of the “home-production commodity” follows a CES type of function with a low elasticity of substitution between male and female labour.

In terms of closure rules, Bolivia is a small economy; therefore, world prices are exogenous. In addition, the Bolivian current account balance and government expenditure on goods and services are assumed to be fixed. Similarly, all tax rates (direct, indirect, import, production) are fixed. We assume that capital is sector specific, while labour is mobile across sectors. The nominal exchange rate is the numeraire.

Finally, to assess the distributional impacts, we use a top-down approach that links the CGE model with a microeconomic analysis module. Specifically, once the macro model is run, changes in the wage rate, income level and prices under climate change scenarios are transmitted to the micro module to calculate changes in poverty. In this specific module, we compute the FGT indicators from Foster *et al.* 1984.

1.2.2. Data

The CGE is calibrated on the SAM from IFPRI et al. 2018. It has 20 activities/commodities, nine of which are agricultural activities: cereals, vegetables, tubers, fruit, other nonindustrial agriculture, soybeans, sugar cane, coca and livestock. To implement our climate scenarios, we grouped these 9 agricultural categories into two types of agriculture, traditional and modern, as they will be affected differently. Traditional agriculture is labour intensive and based on indigenous knowledge and practices, which have been developed over several generations. In the model, this type of agriculture includes the cultivation of cereals,

legumes, tubers, fruits and other nonindustrial crops. Modern agriculture is, however, characterised by the integration of technology and includes the cultivation of crops such as soybeans, sugar cane and coca. Likewise, Bolivian agricultural production is mainly destined for the local market, with only 12% of agricultural production exported. Modern crops are, however, exported more than traditional crops (58% vs. 42%). Soybeans are the main agricultural export product (46% of total agricultural exports), followed by cereals, which make up 25% of total agricultural exports.

The SAM distinguishes three factors of production: capital, land and labour. Land is disaggregated into 3 regions (highlands, valleys and lowlands), and labour is disaggregated according to the level of skills (skilled and unskilled) and gender (male and female). It considers four different institutions: households, firms, the government and the rest of the world. The former is further disaggregated into female/male headed households and whether they live in rural or urban areas. Next to the SAM, we use income elasticity from Morales et al. 2017 and borrow Armington elasticities from Sevillano Cordero, 2012.

To assess the distributional impacts, the micro data we use are based on the National Household Survey (INE, 2019). Although Bolivia has managed to reduce its poverty rate from 59.6% in 2005 to 34.6% of the population in 2018 (WDI, 2018), poverty is still an important issue in Bolivia, as it is still high compared to the rates in neighbouring countries (CEPAL, 2019). Moreover, poverty is not evenly distributed among men and women, with women experiencing a higher national poverty rate (38% vs. 37%, (INE, 2019)) and rural women experiencing a poverty rate 20 percentage points higher than their urban counterparts (52% vs. 32%, (INE, 2019)).

1.3.Scenarios and results

1.3.1. Scenarios

The first simulation is based on an analysis of the direct and indirect effects of the extreme climatic events that occurred in 2013 and 2014 in Bolivia. It considers two different channels: land and capital loss (e.g., machineries, factories) suffered in Bolivia by climatic events (e.g., floods) on one side and world price changes on the other side. We analyse both shocks together since climate change has a global impact on economies, which includes impacts on the evolution of world food prices (Bandara & Cai, 2014; G. C. Nelson et al., 2009). As

Bolivia's main export products are soybeans and cereals, international price variations due to climate change could affect the dynamics of the agricultural sectors.

Specifically, the first simulation considers damage and losses due to climate events in the agriculture sector to be 689.53 million bolivianos (UDAPE, 2015). It was estimated that the damage caused represents losses affecting the land and capital factor of the agricultural sector by 21.9%. To consider the variation in the international prices of agricultural products due to climate change, we use the study by Nelson *et al.* (2009), which gives forecasts for some agricultural and livestock products for the years between 2000 and 2050 using the NCAR (National Centre for Atmospheric Research) model based on the A2 scenario of the IPCC report. Specifically, we consider an increase in the world price of 15% for products from the livestock sector and an increase of 17% for soybeans. The latter increase is also applied to coca and sugar crops, as we consider that these are modern agricultural products. We then compute an average price variation for traditional agricultural products such as rice, corn and wheat. An average price increase of 37% is estimated and applied to Bolivian traditional crop products.

In the second simulation, we consider two different channels as well: a reduction in agricultural productivity and a change in world prices for agricultural commodities. To implement the magnitude of the changes in productivity, we use data from Viscarra *et al.* (2018), who estimate the impacts of climate change on the average yields of certain products for different scenarios in Bolivia. We take into consideration the impacts corresponding to the IPCC A2 scenario, where an estimated 5% drop in the average yield of soybean production and a 12% drop in the average yields of maize and rice in Bolivia will occur. In the model, we apply the variations in soybean yields to modern crops and the variations in maize and rice yields to traditional crops. For the magnitude of changes in world prices of agricultural commodities, we use the same variations as in the first simulation.

1.3.2. Results and discussion

Before discussing the results, let us identify the main transmission channels for our two simulations. On the one hand, the damage to both capital and land (Sim 1) and the reduction in agricultural productivity (Sim 2) have a negative impact on agricultural production. On the other hand, with the increase in world prices for agricultural commodities, some Bolivian producers may be interested in exporting their commodity, but most of them may face an

increase in their input prices if they were using imported commodities. The impacts on the agricultural sectors will spread to the other sectors of the economy.

1.3.2.1. Agricultural sectors

As expected, agricultural production decreases by 16% in the first simulation and 5% in the second simulation. Consequently, agricultural sectors reduce their intermediate consumption, which affects other sectors in the economy. In the first simulation, crops such as soybeans and sugar cane are mainly affected due to their high capital and land intensity, while in the second simulation, traditional crops are hit harder.

Specifically, in the first scenario, soybean production, which is the most capital- and land-intensive crop, is the most affected, with production falling by 17%, followed by sugar cane production (-13%). Subsequently, the production of traditional crops (cereals, fruits, vegetables, and root crops) decreased by 10 to 16%, while coca production was the least affected, with a decrease of 4.85%. Concerning the second simulation, the results also show a decrease in agricultural production for all crops. However, contrary to the previous simulation, traditional crops are the most affected this time, with production losses ranging from 5.4% to 7%. Modern crops are affected to a lesser extent, with production losses ranging from 1.1% to 3.6%.

As far as agricultural employment is concerned, the results show an interesting variability between the different types of crops, given differences in the intensity of crops, in capital or labour but also in the intensity between different types of labour. In Bolivia, traditional crops tend to use mostly unskilled labour, while modern crops require higher skill levels and above all capital for their production. In the first simulation, agricultural employment decreases in all sectors. Indeed, the decline in production means that fewer workers are needed. As a result, agricultural employment falls by 6.34%, with livestock, traditional crops in general and soybeans (to a lesser extent) being the most affected. Given that the livestock and traditional sectors in Bolivia hire mainly low-skilled workers, the employment of unskilled workers registers more severe declines. The second simulation, by contrast, shows some positive employment effects. Indeed, to compensate for productivity losses, some agricultural sectors employ additional workers. Employment increases slightly more for traditional crops than for modern ones, as these are the most labour-intensive agricultural sectors.

1.3.2.2. Non-agricultural sectors

For the nonagricultural sectors, the overall impact on production is negative. In the first simulation, the drop in agricultural production leads to a decrease in intermediate demand, which affects the sectors relying on the agricultural sectors. These sectors will lay off workers. Moreover, the drop in household consumption (see section 3.2.4) has an impact on the production of the different sectors. Specifically, sectors such as the food industry, restaurants and hotels are particularly hit.

Despite a slight increase in agricultural employment in the second simulation, the overall effects on employment are negative (-1.19% in the first simulation and -0.16% in the second simulation). However, the results show substantial differences according to the different types of work and gender

1.3.2.3. Gendered effects on employment

The negative employment effects are reflected in a lower participation rate of households in the commercial sphere. Our results reveal that the loss of employment in the paid labour market leads to an overall increase in the domestic workload of Bolivian households in both simulations. However, these trends vary considerably by gender, with women being particularly more affected than men.

In the first simulation, women suffer particularly from job losses given their strong presence in the traditional agricultural sectors that are the most affected by the climate scenario. Indeed, employment in traditional agricultural sectors is reduced by almost 7%. As shown in Table 1.1, the decrease in employment in the commercial market affects mainly unskilled workers, given their overrepresentation in traditional sectors. This reduction is more significant for women in both rural and urban areas than for men and ultimately leads to increases in their domestic burdens.

In the second simulation, the results also reveal employment losses, although in smaller proportions, and unlike the previous simulation, these are explained by the concentration of female labour in the nonagricultural sectors where women are more active. These sectors include livestock, the commercial industry, the textile industry, and the restaurant and hotel industry, where production is contracted, causing a reduction in employment of close to 3%.

Table 1.1: Gendered impacts of climate change on paid and domestic employment according to skills and location (% change)

Location	Gender	Simulation 1				Simulation 2			
		Skilled		Unskilled		Skilled		Unskilled	
		HOM	PAID	HOM	PAID	HOM	PAID	HOM	PAID
Rural	Male	0,03	-0,07	0,04	-0,03	0,26	-0,17	-0,09	0,04
	Female	0,14	-0,21	0,56	-1,06	0,39	-0,40	0,10	-0,19
Urban	Male	1,21	-0,78	1,64	-1,53	0,42	-0,28	0,09	-0,11
	Female	1,14	-1,07	1,57	-2,41	0,37	-0,37	0,09	-0,15

Source: Calculations based on the CGE model

Note: PAID = paid market labour, HOM = nonmarket household labour

1.3.2.4. Impacts on agents

In both simulations, all agents except firms are negatively affected. Firms' income is derived mainly from capital income. In the first simulation, given the decline in capital stock in agricultural crops, it generates increases in the capital rental rate. This leads to a 6% increase in their income and savings. Concerning the government, we have declines in all sources of income, leading to a drop of total public revenues and savings by 2.02% and 8%, respectively. In the second simulation, for these two agents, the effects follow the same trend but in smaller proportions. Indeed, firms' income and savings increase by 0.29% and 0.32%, respectively, while government income and public savings decline by 0.21% and 1.9%, respectively.

For households, we find interesting results. Rural households are the most affected in both simulations. In the first simulation, we have a decline in wages, which is the main source of household income. However, we see an increase in income from land and capital, which is almost entirely acquired by urban households (see Section 3.1). This ultimately compensates for losses in labour income experienced by urban households. Indeed, household nominal income in rural areas declines by 0.76 % for men and 0.29% for women, while urban household income increases by 1.9% for both men and women. However, given the rise in the consumer price index, due on the one hand to the increase in import prices of agricultural commodities and by the drop in agricultural production, household real consumption decreases. Although consumption declines to the same extent for both men and women (5% and 4.8%, respectively), the disparities between urban and rural areas are particularly large. For example, rural women's

real consumption decreases by 6.7%, compared to 4.4% for urban women. As previously indicated, these particularly negative results for rural women come from their strong presence in traditional agriculture, which was the hardest hit. In effect, job losses for rural women translate into lower incomes and ultimately lower consumption.

In the second simulation, nominal incomes increase for all categories of households due to the slight increase in wages in the agricultural crop sector, which seeks to compensate for the losses in productivity by attracting additional workers. Urban households benefit slightly more here. Indeed, while incomes increase by 2.7% in urban areas for both women and men, in rural areas, they increase by only 2.3% and 2.2% for men and women, respectively. However, due to the increase in the consumer price index (3.25%), household real consumption decreases for all categories of households. Consumption decreases slightly more in male-headed households than in female-headed ones (0.61% vs. 0.59%). As observed in the previous simulation but to a lesser extent, rural households are the most affected. For example, rural women's consumption decreases by 0.89% compared to 0.45% for urban women. This result is explained by the fact that rural women receive their income mainly from labour and benefit less from the increase in capital income that mainly benefits urban households.

Overall, given the fall in consumption across all households and the drop in the production of most sectors, real GDP decreases, especially in the first scenario (-3.09% vs. -0.99%).

1.3.2.5. Impacts on Poverty

At baseline, poverty is higher for women than for men, especially in rural areas where 55.3% of women are poor (Table 1.2). Compared to this baseline situation, both scenarios lead to an increase in poverty, especially in rural areas. Indeed, in the first simulation, we find an increase in poor households, with women being more affected than men in both rural and urban areas. Among women themselves, women in rural areas suffer greater increases in poverty compared to their urban counterparts. In fact, compared to the baseline scenario, the poverty headcount increases by 2.95 percentage points in rural female-headed households, compared to 1.48 percentage points in their urban counterparts. This will result in approximately 58% of female-headed households being classified as poor. Poorer households are particularly hit in both rural and rural areas, especially female-headed households.

Table 1.2: Effects on poverty

Poverty indicator	Baseline scenario (in %)	Simulation scenarios (changes in percentage points)	
		Simulation 1*	Simulation 2*
Rural areas			
Men			
FGT0	51,6	2,73	0,61
FGT1	22,9	2,06	0,32
FGT2	14,3	1,50	0,24
Women			
FGT0	55,3	2,95	0,64
FGT1	24,6	2,12	0,38
FGT2	15,0	1,58	0,25
Urban Areas			
Men			
FGT0	30,8	1,40	0,11
FGT1	10,6	0,57	0,10
FGT2	4,7	0,28	0,04
Women			
FGT0	31,9	1,48	0,11
FGT1	10,9	0,62	0,10
FGT2	4,9	0,30	0,05

Source: Calculations based on the microsimulation model

*Changes in percentage points with respect to the baseline scenario

In the second simulation, poverty increases but to a lesser extent than in the first simulation. Moreover, the impact on the gap between men's and women's increases is also smaller than in the previous simulation. However, as in the previous simulation, the results indicate that women in rural areas are the most affected. In fact, the poverty headcount increases by 0.64 and 0.61 percentage points for female-headed and male-headed households in these areas. Similarly, there is an increase in the depth and severity of poverty for both men and women in rural and urban areas. Again, the vulnerability of the poorest women is becoming worse.

It should be noted that the results of this poverty module are fed by outcomes of the macro CGE model, which lacks information on aspects such as the informal economy in Bolivia. In the same vein, the National Household Survey (INE, 2019) does not provide information on the informal market. Finally, we limit our analysis to monetary poverty indicators without analysing aspects such as impacts on food poverty or access to education for Bolivian households.

1.4.Sensitivity analysis

Thus far, the results suggest that climate scenarios have overall negative effects on the economy and lead to an increase in poverty and gender inequalities. However, the results of CGE models tend to be sensitive to the parameters upon which the model is calibrated (Withey et al., 2016). To test the robustness of our results, we conduct a sensitivity analysis on the parameters assigned for the elasticities of substitution between labour demand, the transformation elasticities assigned on the endogenous labour supply, and the Armington transformation elasticities used between the domestic and the international market. The values assigned to these key elasticities have been increased and reduced by 50%.

The results reveal slight changes for both sensitivity scenarios that do not affect the trends observed in the key variables. Indeed, as shown in Table 1.3, the main macroeconomic variables (employment, consumption, GDP and investment) display negative effects, as do the main microeconomic variables (poverty, inequality), with female-headed households being the most affected. We can therefore conclude that the results are robust since the analysis does not show substantial changes. However, it should be noted that despite not having significant changes in the key variables, when higher elasticity values are used, changes in the key variables tend to be slightly more detrimental to the economy, while lower elasticity values generate slightly fewer negative effects. Therefore, a lower restriction of the model (using high elasticities) is somehow more detrimental for women and for the economy as a whole. Likewise, sensitivity analysis extended to poverty indicators also follows this trend and confirms that the use of higher elasticities makes poverty increase slightly more, especially for rural women.

Table 1.3: Sensitivity analysis for key variables (% change)

Key variables	Simulation 1			Simulation 2		
	Base elasticities	High elasticities	Low elasticities	Base elasticities	High elasticities	Low elasticities
GDP	-1.43	-1.47	-1.41	-0.91	-0.92	-0.89
Employment	-0.14	-0.18	-0.08	-0.03	-0.04	-0.03
Consumer price index	3.88	3.94	3.84	3.13	3.15	3.14
Total Investment	-3.82	-3.91	-3.82	-0.07	-0.09	-0.09
Real consumption of households	-3.67	-3.71	-3.52	-0.55	-0.58	-0.58

Source: Calculations based on the CGE Model

1.5. Concluding remarks

This study provides insight into the possible impacts that climate change could have on the Bolivian economy and women through two different scenarios. The results show that the effects of climate damage on agricultural capital worsen poverty and gender inequalities in Bolivia to a greater extent than in the scenario of declining agricultural productivity. The initial negative impacts on the agricultural sectors are spreading to the rest of the sectors. We find that the most negative effects would be felt by households, particularly rural households, which experience the greatest declines in real consumption. Furthermore, female-headed households are the largest losers, especially in the first simulation.

This analysis also seeks to improve the understanding of the relationships among climate change, domestic work and paid work by explicitly integrating the domestic tasks performed by Bolivian households according to gender into the simulations. In developing countries, women tend to spend significantly more time on domestic work than men (Eastin, 2018; Rubiano-Matulevich & Viollaz, 2019). Our results show that climate change contributes to widening existing gender gaps in the labour market, negatively affecting women's paid employment to a greater extent than that of men. These findings reveal that pre-existing gender disparities in Bolivia are further reinforced in the context of climate change, making Bolivian women more vulnerable than men.

The results of our study are in line with studies that underline the need to integrate vulnerability and gender inequality assessments in the context of climate change (Alston, 2014; Andersen et al., 2017; Eastin, 2018; Wong, 2016), particularly the need to develop climate change adaptation strategies that also seek poverty alleviation (Dasgupta & Baschieri, 2010; Demetriades & Esplen, 2010; Groeschl & Noy, 2020). Our results are crucial, as they can help to build and guide the adoption of early governmental climate change strategies considering key aspects of the Bolivian economy. For example, climate change adaptation policies should focus on gender and consider rural women as a highly vulnerable group. They should also be specific and prioritise the adaptation of crops to climate change, such as cereals, tubers and vegetables, which are staple foods in Bolivia. Additionally, policy options should promote investments in sectors that can reduce women's domestic work (e.g., the water sector or care for children), as this burden may increase due to climate change. Finally, the findings of this work provide far-reaching insights beyond Bolivia, particularly for climate change-affected countries with high levels of gender inequality.

It should be noted that this study analyses short-term effects with a static CGE model and does not consider any climate change adaptation strategies. Extensions of our model would be a dynamic CGE model that integrates long-term scenarios and accompanies them with adaptation policies to mitigate the effects of climate change. Moreover, although the scenarios used in this study considered specific damages to different types of agricultural crops in Bolivia, we think that at a regional level, these same crops could be affected differently because of the wealth of geographical diversity in Bolivia. Therefore, studying specific scenarios at regional levels could also be relevant for future research.

Chapitre 2

II. Climate disaster's impacts on women and food security in Bolivia⁶

Abstract: Throughout Bolivia, the vulnerability of women and men to the impact of climate disasters is not equal due to regional and gender-related differences. Given the diversity of the Bolivian landscape, we analyse a scenario in which specific regional damage occurs in different economic sectors due to adverse climatic events. To that end, using a gendered macro-micro model, we present an ex post analysis of climate disaster-induced damages that occurred between 2013 and 2014 on food security and women's food poverty. The simulation reveals negative impacts on the Bolivian economy, particularly on agriculture. Food availability is reduced, food prices increase, and the economic capacity of households to access food decreases. Consequently, food insecurity and food poverty are exacerbated, with female-headed households suffering the most. The results also reveal negative effects on employment and increased domestic burdens, especially among women in the highlands. These results reveal the need for gender mainstreaming in climate disaster analysis and prevention policies.

Keywords: Climate disasters, General equilibrium model, Food security, Gender, Domestic work

JEL: Q54, C68, J16, O54

⁶ This article is currently undergoing major revisions in the journal *Economic modelling*.

2.1. Introduction

Climate disasters as a consequence of natural or man-made hazards are a challenge faced by many countries worldwide, as they affect economic sectors and populations in different ways (Galbusera & Giannopoulos, 2018). Consequences related to these climatic events are diverse, but most of them have negative impacts on the economy (Kajitani & Tatano, 2018; Wu & Guo, 2021; Xie et al., 2014), particularly on agricultural sectors (Coulibaly et al., 2020; Sivakumar, 2005). The latter is a strategic industry, as it plays a key role in ensuring food security, so the high vulnerability of agriculture in a disaster context must be included in the implementation of policies that seek to ensure food security (Coulibaly et al., 2020; IPCC, 2014; Sivakumar, 2005).

Moreover, future climate change-related effects are expected to increase the frequency and severity of extreme events and disasters (Banholzer et al., 2014; Salinger, 2005; Van Aalst, 2006). It is, therefore, crucial to improve and deepen studies on the potential social risks of these events to promote the adoption of effective preventive strategies. This constitutes a paramount aspect, mainly in the least developed countries that are by far the most affected by climate disasters (Drabo & Mbaye, 2015; Silva & Cernat, 2012; Zorn, 2018).

This paper focuses on Bolivia, which stands out as a country with a high degree of exposure and vulnerability to climate disasters. According to the Global Climate Risk Index⁷, Bolivia made the list of the top 10 most affected countries in the world (Kreft et al., 2016). In this country, vulnerability is due to a significant increase in the number and intensity of adverse natural events but also to limited government resources (García del Castillo & Naranjo Mejía, 2016; Jaramillo, 2009). Bolivia offers an interesting case study, as the occurrence and intensity of natural disasters such as floods, droughts and landslides have increased considerably in recent years, generating large economic losses mainly in the agricultural sectors (BID, 2016; VIDECCI, 2018). The occurrence of adverse natural events is recorded every year, although not always with the same intensity. This led the country to adopt a state of emergency for climatic disasters on several occasions: in 2014, after devastating floods; in 2016, in the face of water shortages generated by the worst drought in almost a quarter of a century; more recently, in 2020, due to fires and droughts. As a result, agriculture, which is a strategic sector for this country, accounting for 30% of total employment, has historically been affected by disasters

⁷ The Global Climate Risk Index 2016 analyses to what extent countries have been affected by the impacts of weather-related loss events (storms, floods, heat waves etc.).

caused mainly by floods and droughts (BID, 2016; UDAPE, 2004, 2015). To some extent, this may explain the country's food security shortcomings. Indeed, despite the government's efforts, the country's food profile is weak, especially on the food availability pillar, given the high dependence on climate and seasonal rainfall distribution of basic agricultural production (Quilla Nina, 2016). Moreover, the amount of food produced per person in monetary value shows a downwards trend since 2006, as does the amount of food provided per capita in kilocalories per day (Kcal). Consequently, the number of undernourished people has not decreased since 2014, affecting approximately 2 million Bolivians (FAOSTAT, 2020).

Beyond the increased frequency and intensity of climate disasters, and as in many developing countries, inequality across the country, particularly gender inequality, is an important issue, as it reveals the existence of specific vulnerable population groups. Women suffer disproportionately during and after disasters due to socioeconomic constraints and inequalities (Brody et al., 2008; Parikh, 2007). Therefore, gender mainstreaming is important when talking about vulnerability to climate disasters, especially in low-income countries where women tend to be harder hit than men (Alston, 2021; Goh, 2012; UN/ISDR, 2008). Bolivia stands out for high socioeconomic and gender inequalities; the gender inequality index has reached 0.45, while the average for Latin America is 0.39 (UNDP, 2015). In the labour market, women work in a narrow range of sectors and are much more likely than men to work in vulnerable jobs (69.7% vs. 58.7%) (WDI, 2018). Gender inequality is even more striking since paid work is mostly carried out by men, who have a participation rate of 82.6% compared to 65.2% for women (WDI, 2020). In contrast, in the nonmarket sphere, unpaid work is mainly carried out by women (Lundvall et al., 2015). Consequently, the high burden of unpaid domestic work borne by women keeps them out of the paid labour market, reducing their economic potential.

In this context of substantial exposure coupled with women's high vulnerability in Bolivia, the occurrence of a climate disaster could have serious consequences on women's economic and welfare. Generally, the focus when studying natural disasters is on the disaster event itself and the economic losses rather than addressing broader risk conditions and development aspects. This may underestimate Bolivia's vulnerability, especially in a postdisaster scenario. On this basis, this paper presents an ex post analysis of the observed effects produced by the climate disasters registered between 2013 and 2014 in Bolivia. This study is conducted for illustrative purposes to assess the risk of disasters produced by the occurrence of these events. Specifically, we address the following research question: *What are*

the linkages between the disasters caused by the observed events and economic activities, and how do they affect food security and gender inequality in Bolivia?

Recent literature has studied these issues mainly using microeconomic analyses and focusing on specific localities. Most of these studies highlight that damage caused by disaster-induced phenomena negatively affects the agricultural sectors and household food security, especially for female-headed households (see, for example, Ajaero, (2017) and Kassie et al., (2015) for rural communities in Nigeria and Malawi, respectively), or studies centred on the Ethiopian city of Addis Ababa (Gebre, 2012; Sisay & Edriss, 2012). The economic literature lacks macroeconomic studies that can provide comprehensive frameworks for analysing disasters and food security from an economy-wide gender perspective.

This paper presents a macroeconomic framework to address these issues, focusing on Bolivia as a case study. To answer our question, we design a specific scenario for agricultural and nonagricultural sectors by using a computable general equilibrium (CGE) model. While there is a large amount of literature on CGE studies related to the assessment of economic losses due to climate change and disasters (Kajitani & Tatano, 2018; Koks et al., 2016; Pauw et al., 2011; Wu & Guo, 2021), few studies have focused on the risks posed by these one-off events in a specific country by adopting ex post historical approaches (Al-Riffai et al., 2012; Montaud, 2019). In Bolivia, some CGE studies address the impacts related to climate disasters, particularly the impacts caused by events such as “El Niño”⁸ (Aliaga & Aguilar, 2009; J. Arenas, 2009; J. C. Arenas, 2014). However, interconnections with dimensions such as food security, specific impacts on vulnerable groups, such as women, and relevant aspects in the nonmarket sphere have been overlooked.

This paper aims to make four major contributions. First, we develop a gender-aware CGE model to take into account the existing gender gaps in Bolivia. The model explicitly integrates domestic production, which is an important aspect for Bolivia, where unpaid household chores are mostly performed by women, especially in rural areas (Ashwill et al., 2011). Second, we consider the impacts on all sectors of the economy, not only the agricultural sectors. Indeed, regional specific shocks are applied to agricultural sectors given the high diversity of the landscape of Bolivia, but damages to other sectors of the economy (construction; transport; electricity, water and gas; forestry and fishing; commercial and social

⁸ El Niño is a climate pattern that describes the unusual warming of the surface waters of the eastern tropical Pacific Ocean leading to extreme climate variability.

sectors) are also considered. Third, since the results of the CGE models are only relevant at the representative household level, we use a top-down approach to delve deeper into the impact of climate disasters on women's food poverty. Finally, beyond the specific case of Bolivia, the contribution of this paper to the existing economic literature on the ex post evaluation of climate disasters is innovative because there are no previous CGE studies that have included the interconnections between climate disasters, food security and gender simultaneously. Furthermore, the model we design can serve as a basis for the analysis of preventive strategies that consider these interconnections in the context of future social risk associated with climate disasters.

The rest of the paper is organised as follows. The second section presents a literature review focused primarily on CGE modelling related to climate disasters, food security, and gender aspects in the commercial and nonmarket spheres of the economy. The third section describes the model and the data used to conduct this study. The fourth section describes the climate scenario and discusses the most relevant results, followed by the policy implications (Section 5). Finally, the sixth section presents the conclusions and some policy recommendations.

2.2. Review of Previous Work

In recent years, climate disasters have become increasingly visible worldwide. A growing body of literature indicates that the agricultural sector is one of the hardest hit by climate disasters, particularly in low-income or less developed countries (Coulibaly et al., 2020; Sivakumar, 2005). Moreover, these disasters are not gender neutral, with women being the most affected and vulnerable (Ahmed & Fajber, 2009; Goh, 2012; Neumayer & Plümper, 2007; UN/ISDR, 2008). In some contexts, this vulnerability may also be associated with greater food insecurity for women (Jungehülsing, 2010; Reyes, 2002).

The literature related to the analysis of disaster losses is extensive and refers to the use of different models, from simultaneous equation econometric models, input–output (I/O) models, and cost–benefit analyses to CGE models. However, the most widely used approaches and especially recent contributions focus mainly on I/O and CGE techniques (Kajitani & Tatano, 2018; Koks & Thissen, 2016). As indicated in the introduction, in this paper, we focus on the CGE approach. This modelling framework indeed seems more suitable for an ex post analysis, as it explicitly captures the multiple links between prices, income, supply and demand in the whole economy (Montaud et al., 2017).

Conventionally, the vast majority of CGE studies adopt a deterministic approach to study conditions related to long-term climate change, especially on agricultural sectors (Andersen et al., 2014; Bezabih et al., 2011; Calzadilla et al., 2013; Gebreegziabher et al., 2016; G. Nelson et al., 2010). There are also a growing number of studies that attempt to include features of shorter-term climate variability, especially with extreme events and disasters (Kajitani & Tatano, 2018; Koks et al., 2016; Pauw et al., 2011; Wu & Guo, 2021). Nevertheless, some aspects, such as the focus on food security and the gender dimension in these CGE studies focused on climate disasters and shorter-term climate variability, have been much less studied.

Following the general trend, CGE studies focusing on Bolivia mainly target the long-term impacts of climate change (Andersen et al., 2014; Calvo, 2014; Jemio et al., 2014; F. Viscarra, 2014; F. E. Viscarra et al., 2018) or the impacts on the Bolivian economy of the effects of extreme events such as El Niño and La Niña during the years 2006–2008 (Arenas, 2014). None include gender or food security dimensions.

Some studies have included an analysis of food security in their CGE model when evaluating future changes in extreme events and disaster risks (for example, Sassi and Cardaci (2013) for Sudan; Montaud et al. (2017) for Niger). Both studies report strong interconnections in exposure to catastrophes and food insecurity, especially for the poorest population. In Guatemala, Vargas et al. (2018) find that the resulting droughts cause significant declines in crop and livestock production, and since agricultural production is essential to ensure food availability, the authors suggest that an appropriate regulatory framework for water distribution is needed. These studies adopt gender-neutral approaches, considering that the effects of disasters are indifferent between men and women.

Although CGE studies focusing on climate disasters did not mainstream gender, the incorporation of this dimension is not a new feature in the literature on CGE modelling. Most CGE studies include a gender dimension in the labour force (e.g. Arndt et al., 2011; Chitiga et al., 2019; Filipski et al., 2011 ; Latorre, 2016; or Siddiqui, 2009 for Pakistan) and/or include the gender of the household head (Cockburn et al., 2007; Escalante et al., 2021; Siddiqui, 2009). Nevertheless, all the aforementioned studies focus only on the market economy and overlook the nonmarket sphere. The introduction of the nonmarket sphere in the CGE modelling literature was pioneered by Fontana and Wood (2000), who propose the extension of a gendered SAM to Bangladesh, integrating domestic work and leisure as new sectors. This framework was extended to different countries and particularly to the analysis of economic and trade policies (e.g. Cockburn et al., 2007 for South Africa; Fontana, 2004 for Bangladesh; Siddiqui,

2009, 2005 for Pakistan). Most of these studies report that trade reforms are more beneficial for men than for women, and some even exacerbate gender inequality by increasing women's domestic workload (Cockburn et al., 2007; Fontana, 2004). An alternative modelling framework is developed by Fofana et al. (2003) for Nepal, which does not include household and leisure activities in the SAM but uses an explicit labour supply function, calculating the maximum time available for work or leisure by using income elasticities of labour supply. Following this approach, Terra et al. (2009) extend the model with endogenous labour supply for Uruguay to include differences by skill level in addition to gender differences. In recent research, Arora and Rada (2020) use a gender-sensitive CGE model that integrates unpaid household tasks and leisure as goods produced within the household economy to assess the effects of technological improvements in agriculture in Mozambique. They show that women free up time with technological progress, which they then reallocate to household activities, mainly the domestic sector.

Our study fills a gap in the literature in linking climate disasters, gender and food security with Bolivia as a case study.

2.3. Methodological Framework and Data

To evaluate the regional impacts of climate disasters on women's food security and poverty in Bolivia, we use a static CGE model based on PEP 1-1 from Decaluwé et al. (2013), several assumptions of which we have changed to take into account the specifications of our study. Given that climate disasters are one-off events, we consider a static CGE model to be appropriate for our analysis, as it has the advantage of capturing the second-order effects of these climate shocks on economic activities, women and food security. Although the standard model is described in Decaluwé et al. (2013), we present below the main features of the CGE model as well as the changes we have introduced.

2.3.1. The CGE model⁹

The CGE model incorporates the classical features of general equilibrium. It covers the global linkages of an economy and is able to analyse the interactions that may exist between regional climate shocks and economic agents. In the model, the production function of technology assumes constant returns to scale, and producers have the possibility of selling their

⁹ All equations and variables of the CGE model can be found in the Appendix A.2-1

products either on the local market or on the international market, following a constant elasticity of transformation (CET) function. Production follows a Leontief-type function between value added and intermediate consumption at the top level and for each activity. Value added is a constant elasticity of substitution (CES) type of function of composite labour and composite capital. Composite capital is a CES function between types of machinery and land. Composite labour is disaggregated according to skill levels following a CES function, and at the next level, each type of skill is further disaggregated between men and women.

In contrast to the standard PEP 1-1 model and drawing on the work of Fontana and Wood (2000), Fofana et al. (2003) and Terra et al. (2009), we consider an endogenous labour supply that integrates a gender dimension and a time constraint that depends on the time households devote to their market and nonmarket activities.

Indeed, following Fofana et al. (2003), we consider that each individual in the household has a fixed amount of time (measured in hours) that he or she can allocate between leisure, a paid job in the market sphere of the economy, and the production of a nonmarket commodity (taking care of children, preparing meals, etc.).

Technically, we are modifying our Stone and Geary utility function by including gender leisure and household home production, as developed by Graham and Green (1984). Households maximise their utility under the constraint of their full income (Fofana et al., 2003). Full income is the sum of the different incomes from the market sphere of the economy, nonlabour incomes (such as transfers), and income from home production. This activity is actually unpaid but valued as its opportunity cost on the labour market. We assume that home-production commodities are only consumed by households.

Demand functions for market commodities (Equation 1), home commodities (Equation 2) and labour supplies (Equations 3 to 6) are obtained from the programme maximisation of household utility¹⁰.

(1)

$$PC_i C_{i,h} = PC_i C_{i,h}^{MIN} + \left(\frac{\gamma_{i,h}^{LES}}{(1 - z_h^{femnq} - z_h^{malnq} - z_h^{femq} - z_h^{malq} - z_h^{hom})} \right) \left(CTH_h - \sum_{ij} PC_{ij} C_{ij,h}^{MIN} \right)$$

With:

¹⁰ The calibration of the different parameters of these equations can be found in Appendix A.2-2

PC_i : Purchaser price of composite commodity

$C_{i,h}$: Consumption of commodity i by type h households

$C_{i,h}^{MIN}$: Minimum consumption of commodity i by type h households

CTH_h : Consumption budget of type h households

z_h^{femna}, z_h^{fema} : Household H's share of female home consumption (unskilled and skilled)

z_h^{malna}, z_h^{mala} : Household H's share of male home consumption (unskilled and skilled)

z_h^{hom} : Marginal budget shares of allocation of supernumerary income between market and home-produced outputs

$\gamma_{i,h}^{LES}$: Marginal share of commodity i in household h consumption budget

(2)

$$CZ_h P_h^{hom} = CZ_{i,h}^{MIN} P_h^{hom} + \left(\frac{z_h^{hom}}{(1 - z_h^{femna} - z_h^{malna} - z_h^{fema} - z_h^{mala} - z_h^{hom})} \right) \left(CTH_h - \sum_{ij} PC_{ij} C_{ij,h}^{MIN} \right)$$

With:

CZ_h : Consumption of home-produced commodities by type h households

P_h^{hom} : Purchase price of home-produced commodities by type h households

$CZ_{i,h}^{MIN}$: Minimum consumption of home-produced commodities (LES consumption function)

(3) and (4)

$$LSFNQ_h = MAXHOUR_h^{femna} - LZFNQ_h - z_h^{femna} \frac{(CTH_h - \sum_{ij} C_{ij,h}^{MIN} PC_{ij})}{[WZFNQ_h (1 - z_h^{femna} - z_h^{malna} - z_h^{fema} - z_h^{mala} - z_h^{hom})]}$$

$$LSFQ_h = MAXHOUR_h^{fema} - LZFQ_h - z_h^{fema} \frac{(CTH_h - \sum_{ij} C_{ij,h}^{MIN} PC_{ij})}{[WZFQ_h (1 - z_h^{femna} - z_h^{malna} - z_h^{fema} - z_h^{mala} - z_h^{hom})]}$$

With:

$LSFNQ_h, LSFQ_h$: Household H female market labour supply (unskilled and skilled)

$MAXHOUR_h^{femna}, MAXHOUR_h^{fema}$: Maximum time available for skilled/unskilled females in household h

$LZFNQ_h, LZFQ_h$: Household H female time used to produce home commodities (unskilled and skilled)

$WZFNQ_h, WZFQ_h$: Female wage rate related to home production work (unskilled and skilled)

(5) and (6)

$$LSHNQ_h = MAXHOUR_h^{malnq} - LZHNQ_h - z_h^{malnq} \frac{(CTH_h - \sum_{ij} C_{ij,h}^{MIN} PC_{ij})}{[WZHNQ_h(1 - z_h^{femnq} - z_h^{malnq} - z_h^{femq} - z_h^{malq} - z_h^{hom})]}$$

$$LSHQ_h = MAXHOUR_h^{malq} - LZHQ_h - z_h^{malq} \frac{(CTH_h - \sum_{ij} C_{ij,h}^{MIN} PC_{ij})}{[WZHQ_h(1 - z_h^{femnq} - z_h^{malnq} - z_h^{femq} - z_h^{malq} - z_h^{hom})]}$$

$LSHNQ_h, LSHQ_h$: Household H male market labour supply (unskilled and skilled)

$MAXHOUR_h^{malnq}, MAXHOUR_h^{malq}$: Maximum time available for skilled/unskilled males in household h

$LZHNQ_h, LZHQ_h$: Household H male time used to produce home commodities (unskilled and skilled)

$WZHNQ_h, WZHQ_h$: Male wage rate related to home production work (unskilled and skilled)

To produce the home production commodity, households only use labour. Consequently, the production of home commodity is a CES function between male labour and female labour. To reflect the rigidity between male and female labour and following Fontana and Wood (2000), we set up a low value of substitution elasticity. The lower the elasticity of substitution, the more it reflects rigidity between the roles of men and women in the household (Fontana et al., 2020). Each type of labour is further disaggregated between skilled and unskilled labour with a low elasticity of substitution.

The model distinguishes four different institutions: households, firms, the government and the rest of the world. Households are broken down according to their location (highlands, valleys and lowlands) and according to gender (male and female). Their income comprises labour income, capital income and transfers from other agents.

Households use their income for tax payments and savings, but mainly for consumption. Savings represent between 10% and 14% of total household budgets, with households in the valleys saving the most and those in the lowlands saving the least, especially female-headed households in this region, who allocate 0.3% less money to savings than their male counterparts.

The government collects direct and indirect taxes and receives transfers from other agents. More than 50% of its income comes from indirect taxes. It mainly uses its income for

public expenditures (mainly on nontradable commodities) and for the payment of transfers to nongovernmental agents. The remainder constitutes savings. Firm income comes from capital income (96.54%) and transfers from other institutions. They pay income taxes, dividends and transfers to other agents, and the remaining income constitutes savings.

2.3.2. Food security and food poverty

According to the Food and Agricultural Organisation (FAO), food security rests on four pillars: food availability, food access, stability and vulnerability of supplies, and biological utilisation (FAO, 2006). Our analysis considers three of these pillars: food availability, food access, and food vulnerability.

First, the analysis of food availability determines whether people have material access to food. In our model, this indicator is measured by changes in agricultural production. In addition, we also add the calculation of more local indicators, particularly the change in the food supply for local markets. Indeed, given that food production can be either exported or sold locally, we believe this indicator gives us more precision on how much food is available on the local market.

Second, the dimension of access to food is captured through indicators such as the index variation of goods and food prices but also changes in real household consumption of agricultural goods. This dimension is evaluated at the regional level for both male- and female-headed households.

Third, the food vulnerability dimension is based on the calculation of two indicators: the value of food imports compared to the value of local food demand, which reflects the importance of imported food in the local food market, and the ratio of food imports relative to total merchandise exports. Following FAOSTAT (2020), this indicator captures the adequacy of foreign exchange reserves to pay for food imports.

Finally, we carry out an analysis of food poverty, which is defined as insufficient economic access to an adequate quantity and quality of food to maintain a nutritionally satisfactory and socially acceptable diet (O'Connor et al., 2016). This analysis is based on the extreme poverty line. Technically, we link our macro model to microsimulations: once the CGE model is run, changes in the wage rate, income level and prices are transmitted to the micro module. This module integrates gender and regionally disaggregated data to estimate regional changes in food poverty among men and women.

2.3.3. Data

The main source of data comes from a social accounting matrix (SAM). Specifically, we use the 2012 SAM developed by IFPRI et al. (2015), which offers a regional disaggregation of the agricultural sector (highlands, valleys and lowlands). This aspect is important for the present study, given the different exposures to climate change of the agricultural sectors in the three regions. The initial SAM provided a breakdown of the agricultural sector into nine crops, which were aggregated into three groups representing three types of agriculture (traditional, livestock and modern). Among the regions, the use of agricultural production factors, whether in traditional or modern agriculture, as well as the type and destination of agricultural production, vary greatly according to location.

For instance, the highlands and valleys tend to have a more traditional agricultural production system, while modern agricultural production is predominant in the lowland areas (Column 3 Table 2.1). Bolivian traditional agriculture is labour intensive and based on indigenous knowledge and practices that include the cultivation of cereals, legumes, tubers, fruits and other nonindustrial crops. Conversely, modern agriculture is characterised by the integration of technology and includes the cultivation of crops such as soya, sugar cane and coca. In general, Bolivian agriculture is labour intensive in all regions, with unskilled labour being the main factor, especially in traditional agriculture (Columns 4-6).

Table 2.1: Regional agricultural production and factor intensity by type of agriculture (%)

Location	Type of agriculture	Production by region	Factor intensity			
			Skilled labour	Unskilled labour	Capital and land	Total
Highlands	Traditional	71.14	33.43	52.73	13.84	100.00
	Modern	9.28	41.67	47.98	10.35	100.00
	Livestock	19.58	43.65	39.64	16.71	100.00
	Total agriculture	100.00	35.99	50.16	13.85	100.00
Valleys	Traditional	52.87	24.63	55.51	19.86	100.00
	Modern	9.23	29.27	54.55	16.18	100.00
	Livestock	37.90	45.49	37.79	16.71	100.00
	Total agriculture	100.00	31.65	49.88	18.47	100.00
Lowlands	Traditional	27.06	32.67	41.95	25.38	100.00
	Modern	46.81	18.52	10.48	70.99	100.00
	Livestock	26.13	44.67	38.62	16.71	100.00
	Total agriculture	100.00	30.29	29.04	40.67	100.00

Source: Own elaboration from the Social Accounting Matrix, 2012.

Eighty-eight percent of agricultural production is sold on the local market. Modern agricultural production is the most exported, with soya being the main export product (46% of total agricultural exports). The lowland region, with its modern agricultural production methods, accounts for 56% of total agricultural exports.

In total, the model has 26 activities (9 agricultural) and 30 commodities, including nine agricultural goods: cereals, vegetables, tubers, fruits, other nonindustrial agricultural activities, soya, sugar cane, coca and livestock.

From the SAM, we can see that Bolivian household income comes mainly from labour in all regions (Table 2.2). However, the share of this income source is more significant in male-headed households than in female-headed households (84.98% vs. 75.18%).

Table 2.2: Source of household income by gender and region (%)

Location	Gender	Source of income		
		Labour	Capital/Land	Transfers
Highlands	Male	87.20	0.74	12.06
	Female	77.90	0.65	21.45
Valleys	Male	81.19	1.50	17.31
	Female	66.58	1.26	32.16
Lowlands	Male	85.75	3.62	10.63
	Female	79.88	3.40	16.73
National	Male	84.98	2.12	12.90
	Female	75.18	1.89	22.93

Source: Own elaboration from the Social Accounting Matrix, 2012.

In the valley region, the share of income coming from labour is lower than that for the other regions and notably for women. This could be explained by the fact that many of these communities are undergoing a process of conversion to livestock and nonagricultural activities to link up with the market and increase their income (Pacheco et al., 2003). This leads to a decrease in the importance of agricultural activities that provide the bulk of labour income. Transfers also constitute an important share of household income, especially in female-headed households in the highlands and valleys. Finally, households receive land and capital incomes. Although this source represents the smallest share of total income (between 1% and 4%), households in the lowland region and particularly those headed by men receive the largest share. Indeed, 52% of this income is received by men, followed by 17% for women in the same region.

Next to the SAM, we draw on estimates of time allocated to household tasks and estimates of key elasticities for the CGE. Based on Escalante and Maisonnave (2021), the amount of time spent on domestic tasks in Bolivia was determined using time-use surveys, which indicate that women spend up to four times more time doing domestic chores than men (Canelas & Salazar, 2014; CEPAL, 2001). In addition, given the absence of time-use data per level of education, we used the Colombian time allocation estimates from Rubiano-Matulevich and Viollaz (2019). Based on these studies, it was estimated that, on average, unskilled women allocate 5.47 hours per day to household work, while skilled women allocate 4.1 hours per day. Unskilled men, however, allocate only 1.25 hours to domestic chores, compared to 1.23 hours for skilled men.

We also use data from the National Household Survey (2019). This database is used for the microsimulation module that allows for the analysis of food poverty. Finally, the values of the elasticities required for the model are based on specific studies for Bolivia. Specifically, we use the income elasticities of Morales et al. (2017). The Armington and CET elasticities are based on the estimates of Sevillano Cordero (2012). In addition, the labour market elasticities are taken from Fofana et al. (2003) and Fontana and Wood (2000).

2.4. Climate Scenario and Results Discussion

Scenario

Our climate scenario is based on a study on damages due to adverse climatic events in Bolivia conducted by the Unit for the Analysis of Social and Economic Policies from Bolivia (UDAPE, 2015). Specifically, the study considers an analysis of the 129 Bolivian municipalities that were declared to be in a state of emergency in the period from October 2013 to May 2014. During the analysis period, 52 municipalities were recorded as having floods, 27 as having hailstorms, and 10 as having landslides, and there were 40 cases of mixed events among floods, hailstorms and landslides. The study assesses the multisectoral effects of adverse climate events, quantifying the damage and estimating losses in the social, infrastructure and economic sectors. Based on these estimates, our scenario includes damages to agricultural and nonagricultural sectors due to climate disasters registered between 2013 and 2014.

To calibrate our scenario given the data at the departmental level, we aggregated the departments into the three regions we have in the model (highlands, valleys and lowlands) and the agricultural products into three categories (traditional, modern and livestock) (see Table 2.3). For nonagricultural sectors, we use the estimations of damages and losses from UDAPE (2015) and see that transport and construction are the sectors most affected by climate disasters (Table 2.4).

Table 2.3: Value of lost production in agricultural crops and livestock by region (in millions of Bolivianos)

	Highlands	Valleys	Lowlands	Total
Traditional	139.22	137.80	269.38	546.40
Modern	13.35	48.56	81.21	143.13
Livestock	0.03	359.39	0.00	359.42
Agriculture and Livestock	152.61	545.75	350.59	1048.95

Source: Authors, with information from UDAPE (2015)

Table 2.4: Value of lost production in the nonagricultural sectors (Millions of Bolivianos)

	Damages	Losses	Total
Transport	470.46	21.23	491.69
Water and sanitation	99.07	3.21	102.28
Electricity	5.99	1.55	7.54
Telecommunications	1.51	1.28	2.79
Forestry and fishing	0.00	37.40	37.40
Health and social	73.63	17.76	91.39
Housing/construction	229.58	0.77	230.35
Nonfarm sector	880.25	83.19	963.44

Source: Authors, with information from UDAPE (2015)

Estimates of damages and losses for all sectors correspond mainly to infrastructure and capital losses. Technically, in the CGE model, the damages affect the initial capital stock in both agricultural and nonagricultural sectors. In the agricultural sectors, it was estimated that losses affected the capital stock of traditional agricultural sectors by 38.3%, 25.3% and 38.0% in the highland, valley and lowland regions, respectively; the stock of modern agricultural sectors by 29.2%, 57.3% and 3.9% for the same three regions; and the stock livestock sector by 2% in the highlands and 90% in the valleys. For the nonagricultural sectors, a decrease in capital stock was estimated at 21.7% for the transport sector; 23% for electricity, water and gas; 12.6% for forestry and fishing; 18.6% for construction and commerce; and 10.1% for the social services sector.

Results and discussion

2.4.1. Macro results

The results reveal that climate disasters have detrimental effects on macroeconomic indicators (Table 2.5). Indeed, climate disasters not only have a negative impact on the sectors directly exposed, where production decreases considerably but also affect sectors that were not directly affected. Indeed, directly impacted sectors see their production decrease as expected, and therefore they decrease their intermediate consumption from other sectors, which were not initially affected by the climate impacts.

As a result, production decreases in most sectors, leading to a negative trend in total employment (1.14%) in the market sectors. The release of workers, mainly from the agricultural sectors, where outflows reach 15%, translates into a decrease in wage rates, with a greater

reduction in the unskilled wage rate (Table 2.5). A decrease in wages affects household incomes since labour revenues are their main source of income.

Another transmission channel is derived from the variation in local prices. Indeed, the decline in production leads to a shortage of products, particularly agricultural products, leading to an increase in the prices of final goods. This results in a 5.78% increase in the price index. As a result, the fall in wages combined with the increase in local prices has negative effects on real household consumption, which decreases significantly, affecting women more than men (-3.63% vs. -3.50%).

Table 2.5: Macro indicators (percentage change from baseline)

	Simulation
Real GDP at basic prices	-3.25
Consumer price index	5.78
Real consumption budget of male-headed households	-3.50
Real consumption budget of female-headed households	-3.63
Total investment expenditures	-1.71
Employment in market sectors	-1.14
Wage rate (skilled workers)	-0.71
Wage rate (unskilled workers)	-2.16

Source: Authors' calculations.

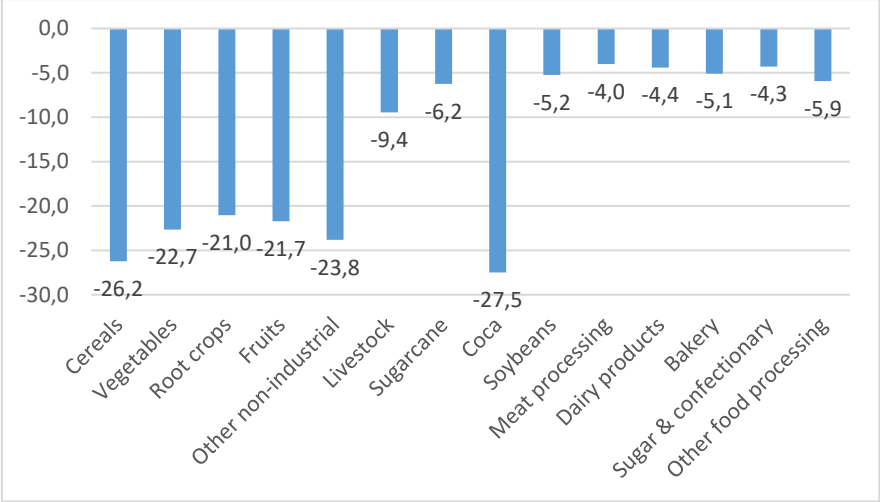
Consequently, with real consumption falling sharply and production being adversely affected in most sectors of the economy, the impact on real GDP is also negative (-3.25%). Our results are comparable with several studies in Bolivia that report a drop in GDP due to climate change-related events (Andersen et al., 2014; F. Viscarra, 2014).

2.4.2. Sectoral results

As expected, the agricultural sectors suffer the greatest damage under the climate scenario. At the national level, agricultural production declines by 15.25%, with traditional agriculture recording the largest decline. Indeed, as shown in Figure 2.1, the production of traditional crops such as cereals, fruits, vegetables, and root crops registers the greatest losses (more than 20%). As far as modern production is concerned, coca and sugar cane crops, to a lesser extent, show significant declines, while soybean production, which is the main modern

agricultural product, is down by only 5.2%. Finally, the production of processed foods, such as meat, milk, or bakery products, shows slight declines, ranging between 4% and 6% (see Figure 2.1).

Figure 2.1: Agricultural and food production (percentage change from baseline)



Source: Calculations based on the CGE model

The impacts are not uniform across regions. The highlands and valleys are relatively more affected, as they devote most of their production to traditional agriculture. The valley region faces the highest losses (almost 40%). This is mainly due to the damage of climatic disasters in the livestock sector, which is concentrated only in this region but also to damage to crops such as sugar cane and coca, which are modern crops produced mainly in this region and are severely affected. In contrast, the lowland region is the least affected, with a drop in production of only 5%. The fall in wages (Table 2.5) explains why the lowlands perform better than the two other regions. Indeed, this region is the most export-oriented, and the drop in wage rate makes Bolivian exports relatively more competitive for commodities such as soya. As a result, competitiveness gains in this region manage to partly offset its losses.

For most nonagricultural sectors, a drop in production is also observed. The most significant declines occurred primarily in the sectors directly affected (transport; electricity, water and gas; forestry and fishing; construction; and commercial and social services). These sectors recorded losses of between 1% and 4%, with construction being the most affected sector (-4.3%). There are also significant declines in the commercial and food industries, which are down by 4% and 5%, respectively. Moreover, the negative effects extend to some capital-intensive nonagricultural sectors. Indeed, these sectors are affected by the negative trend in investment that leads to a reduction in the production of investment goods.

Declining production means that fewer workers are required to sustain production in each sector. Unsurprisingly, the most drastic declines occur in the agricultural sector, with employment in the traditional agricultural sectors being more affected than in the modern agricultural sectors (-17.5% vs. -14.2%). Moreover, given that the Bolivian traditional agricultural sector employs mainly unskilled workers (see Table 2.2), the effects of climate disasters are more damaging to those who are unskilled. There is also a decline in employment in nonagricultural sectors, mainly those linked to agricultural sectors, such as the food industry, where employment decreases by 10%.

The results by gender show that women's employment is more affected than men's employment, mainly when women are less skilled. This is due to their strong presence in traditional agricultural activities, which are severely hit by climate disasters. As a result, employment losses in sectors where women are most present, such as traditional agriculture in all regions, livestock farming in the lowlands, or commercial industry, register losses of over 20%.

2.4.3. Impact on agents

Households are severely affected given the decline in wages, which is their main source of income. This drop is greater among female-headed households than among male-headed households (-3.63% vs. -3.5%). The results also reveal an increase in income from capital and land for all households. Indeed, the reduction of capital, mainly in the agricultural sector due to climatic disasters, makes the stock of capital and land scarce, which ultimately leads to an increase in their rental rate. Regional analysis shows interesting results. Households located in lowland regions benefit most from increases in capital and land income and are thus best able to compensate for their losses of labour income. In this region, households receive the largest share of total capital income, particularly those headed by men (see Table 2). Overall, the total disposable income of households shows slight increases between 1% and 2%, with male-headed households in the lowland region benefiting the most. Nevertheless, given the sharp increase in prices, real household consumption is decreasing for all households, with women in the highland region experiencing the largest declines in real consumption, while those in the lowland region are the least affected.

Moreover, the negative employment impacts described in Section 2.4.1 are also reflected in lower participation rates in the formal labour market for households. Our results reveal that the loss of employment in the commercial sphere leads to an overall increase in the

domestic workload of Bolivian households by 1.64%. However, changes in market employment and household burdens are not uniform across regions and genders. Indeed, in the commercial sphere, women are the most affected, seeing their market employment fall by 2.59%, compared to a drop of only 0.66% for men. This leads to an increase in domestic burdens, which is greater for women than for men (1.66% vs. 1.59%). At the regional level, the same trend is observed in all regions. That is, reductions in market employment lead to an increase in household burdens that are greater for women than for men, particularly in the valleys and lowlands. However, the results also reveal disparities even among women when skill levels are considered.

Table 2.6: Impact of climate disasters on the female labour market by region and skills
(percentage change from baseline)

Location	Skilled female labour		Unskilled female labour	
	Market work	Domestic work	Market work	Domestic work
Highlands	-1,37	1,08	-5,00	1,94
Valleys	-1,41	1,13	-5,16	2,01
Lowlands	-2,12	1,68	-6,51	2,55
Total	-1,69	1,34	-5,52	2,15

Source: Calculations based on the CGE model

As we can see in Table 2.6, unskilled women experience greater declines in market employment than skilled women in all regions, leading to heavier burdens of domestic tasks for unskilled women, with those women living in the lowlands and valleys being the most affected.

The government's income decreases by 1.08%, mainly due to the drop in indirect taxes collected, and savings fall by 5.16%. For firms, given the increase in the rental rate of capital and land, their income and savings recorded a slight increase of 1.7%.

2.4.4. Impact on food security and food poverty

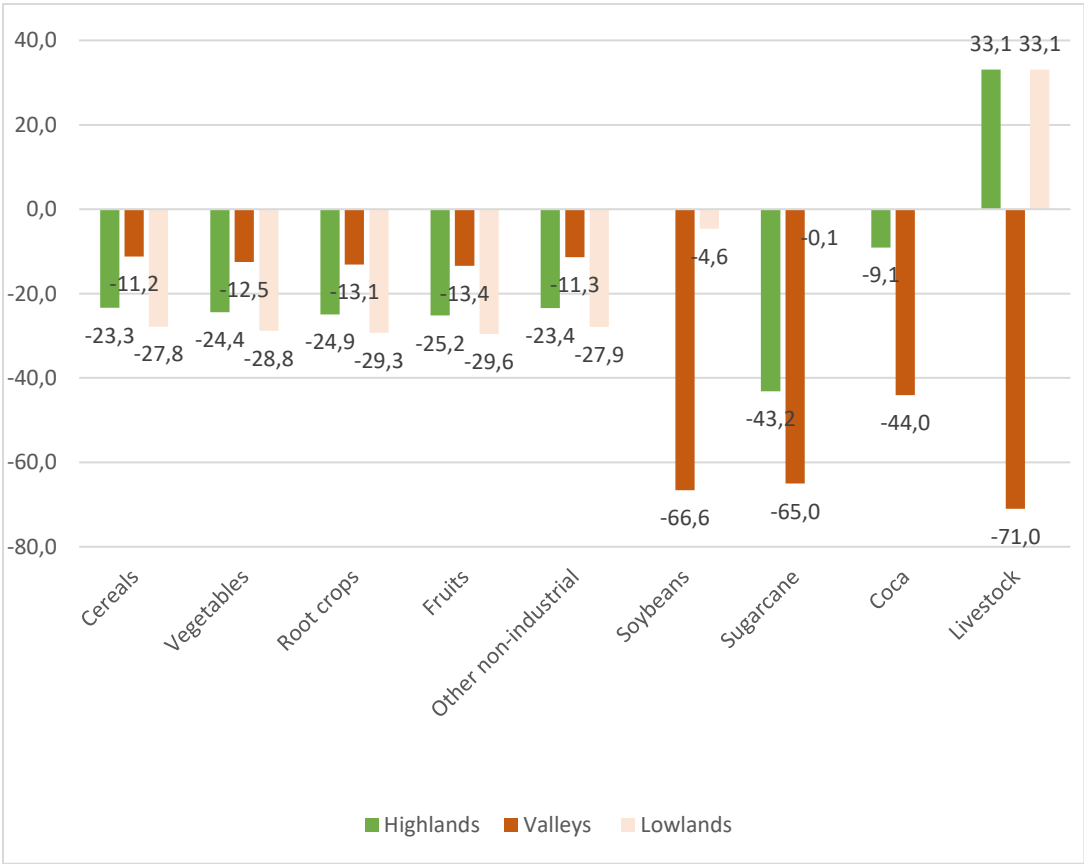
As mentioned in Section 2.4.2, agricultural and food production declined significantly, with the production of traditional crops being the most affected. This affects the supply of agricultural products destined for the domestic market, which is essential to ensure food availability. From a regional point of view, agricultural production in the valleys registers the most significant decline (Figure 2.2). These negative results are largely explained by the strong

decline in the supply of production in the livestock sector, which shrinks by approximately 70% in this region, combined with strong decreases in the production of modern crops such as coca, sugar cane and soybeans.

Interestingly, the results for the soybean crop are not the same in the lowlands. Indeed, in this region, the supply of this crop is reduced by only 4.6%, suggesting that the lowland region is better prepared to counteract the effects of disasters and can supply its local market with greater capacity. Finally, in the highland region, the results reveal that the supply of traditional agricultural products shows the largest decrease, but some decreases are also observed in the supply of sugar cane and coca crops.

Consequently, in terms of food availability, the decrease in agricultural and food production (Figure 2.1), as well as the decrease in the supply of agricultural products destined for the domestic market (Figure 2.2), reveal that the effects of climatic disasters are very damaging for Bolivia, especially for the valley regions and for traditional crops.

Figure 2.2: Supply of agricultural production destined for the domestic market by region (percentage change from baseline)

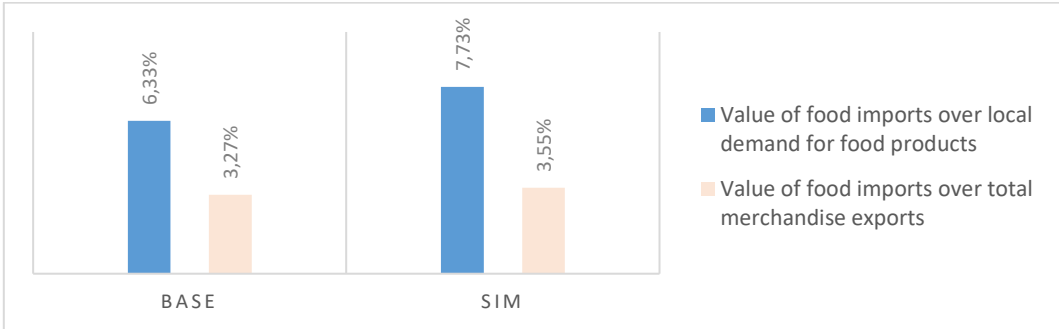


Source: Authors' calculations

The decline in production for the local market, and more specifically in agricultural and food production, creates a shortage in the local food supply that is covered by an increase in imports. Indeed, we find an increase in the import of agricultural products, especially traditional products and livestock. This increase is due to an increase in the local prices of agricultural products, with traditional and livestock products experiencing the largest increases. Consequently, livestock imports increase the most, followed by cereals, vegetables and fruits, which are basic staples in the daily diet of Bolivians. Similarly, there is also an increase in processed foods such as meat, milk and baked goods. Although increased imports are necessary to cover the needs of Bolivian households (mainly in a postclimate disaster context), in the long run, a continued increase in agricultural imports could exacerbate the risk of food insecurity.

Finally, regarding food vulnerability, we find that the value of food imports compared with the value of local food demand increases by 1.4 percentage points with respect to the baseline scenario (Figure 2.3). Likewise, the value of food imports (excluding fish) relative to total merchandise exports increased from 3.27% in the baseline year to 3.55% for the climate disaster scenario. The increase in this indicator is particularly negative, as it captures the adequacy of foreign exchange reserves to pay for food imports.

Figure 2.3: Food security indicators (in percentages)



Source: Authors' calculations

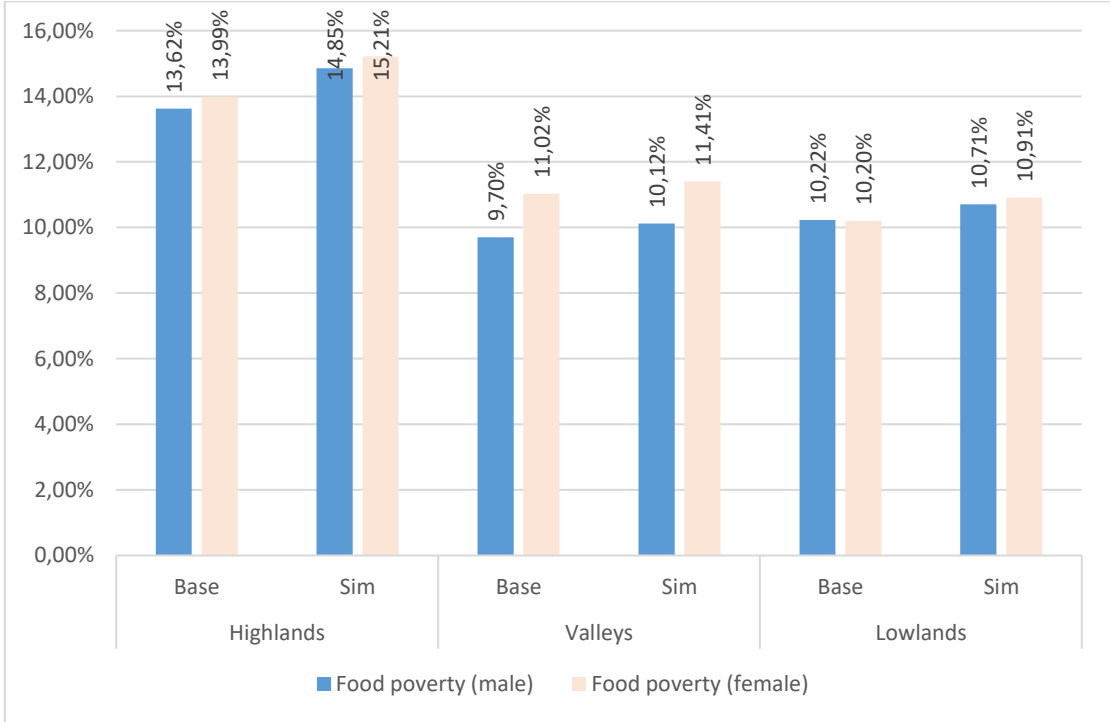
Note: SIM = Climate disaster scenario, Base = Baseline scenario.

At the economic access level, we find a significant increase in the level of prices, a fall in household labour incomes, and increases in income from capital and land, particularly for households in the lowland regions. However, despite the increase in revenues from some sources, no household manages to improve its ability to afford food. This result is interesting because it shows that food prices are the channel that most threatens households' economic access to food. While all households face a drop in their economic access, female-headed households experience greater declines in food consumption than male-headed households,

especially in the highland and valley regions. Furthermore, it should be noted that the decline in food consumption is greater for traditional products such as cereals, fruit and vegetables.

Finally, to evaluate the impact of climate disasters on the evolution of food poverty, we use the extreme poverty line as a food poverty baseline and calculate the changes in the incidence of food poverty. As shown in Figure 2.4, the effects of the climate scenario on food poverty are quite interesting. In the baseline situation, food poverty is higher for women than for men in all regions. The highest levels of food poverty are observed for both men and women in the highland region. After climate disasters, a higher number of households experience food poverty, especially in the highlands for both men and women, with women being systematically more affected than men.

Figure 2.4: Effects of climate disasters on food poverty by region and gender (in percentages)



Source: Calculations based on the microsimulation model

Note: SIM = Climate disaster scenario, Base = Baseline scenario.

2.5.Sensitivity analysis

In the following section, we present a sensitivity analysis that consists of studying the robustness of the results we obtain. Given that in our CGE model we include aspects of gender and an endogenous labour supply in the labour market that are not common, this analysis is

fundamental to analysing how sensitive our results are. In particular, the analysis stipulates variations applied to the values assigned to parameters of labour demand and supply and to parameters linked to the production and consumption of goods produced in the household.

The labour market results are relatively sensitive to the income elasticities of labour supply (LELASs) and to the elasticities of substitution between male and female labour for both skilled (Sigma_LDQ) and unskilled (Sigma_LDNQ) workers. In fact, we find that the maximum time available to perform housework and market work (MAXHOURS) is substantially reduced when low labour elasticities are used and expanded with high elasticities, but the simulation results do not significantly change. Furthermore, low elasticities of substitution between male and female labour (skilled and unskilled) widen the differences in wage effects and have slightly more detrimental effects on the economy, while the use of high elasticities tends to have less detrimental results. Once again, however, the simulation results vary slightly, and the trends observed for the key variables do not show significant changes (see Table A.2.1).

Table A.2.1: Sensitivity analysis for key variables in the labour market (in %)

	Low elasticities (-30%)	High elasticities (-30%)
Real GDP at basic prices	-3.30	-3.21
Consumer price index	5.82	5.74
Real consumption budget of male-headed households	-3.61	-3.59
Real consumption budget of female-headed households	-3.64	-3.62
Employment in market sectors	-1.21	-1.07

Source: Authors' calculations

The same trends are observed with the elasticities of substitution in male and female household production (sigma_zlab), i.e., the use of low elasticities turns out to be more detrimental to the economy. However, the latter are much less sensitive, as the simulation results are almost unchanged. We also tested different values for the minimum subsistence of domestically produced goods, as arbitrary values were assigned for Bolivia based on previous studies (see, e.g., Fofana et al., 2003, 2005). The more we reduce the total value of home-produced goods initially assigned, the more detrimental the results become for the economy. However, these changes occur in small proportions, and we find no change in the trends of our results.

Table A.2.2: Sensitivity analysis for full key variables (in %)

	Low elasticities (-30%)	Low elasticities (-15%)	High elasticities (+15%)	High elasticities (+30%)
Real GDP at basic prices	-3.37	-3.31	-3.19	-3.11
Consumer price index	5.9	5.84	5.72	5.64
Real consumption budget of male-headed households	-3.64	-3.62	-3.59	-3.57
Real consumption budget of female-headed households	-3.65	-3.64	-3.61	-3.59
Employment in market sectors	-1.33	-1.24	-1.03	-0.91
Domestic work male	1.82	1.74	1.4	1.14
Domestic work femal	1.8	1.75	1.57	1.45

Source: Authors' calculations

In Table A.2.2, we present the results on the key macroeconomic variables (employment, consumption, price index and domestic labour) under uniform variations of +-15% and +-30%, applied to all parameters and elasticities described previously in this section jointly. The results reveal slight changes in the results, but these do not affect the trends observed in the key variables.

Therefore, we can conclude that the results are robust, as the analysis has not shown substantial changes. However, it is worth noting that higher restrictions in the model (using low elasticities), mainly on labour supply and demand, have particularly more negative effects, so it would be relevant to assign values that accurately reflect the elasticities in the labour market. Finally, extending the sensitivity analysis to food poverty indicators, the trend also holds with variations in poverty rates quite minimal.

2.6. Concluding remarks and policy recommendations

We evaluated the potential impacts of climate disasters on food security and women's well-being in different regions in Bolivia. The findings reveal negative impacts on the economy, with the agricultural sector being seriously affected and the effects spreading to many nonagricultural sectors. Furthermore, analysing the results by crop type and by region of production reveals that traditional crops and the regions where they are produced record the highest losses. The particularly negative effects on the agricultural sector ultimately affect food security in multiple dimensions. Overall, the climate disaster scenario poses a considerable risk to food security, mainly due to the decrease in food production affecting food availability and the increase in the relative price of nutrients affecting access to food. In addition, the results reveal a greater dependence on imports for processed foods.

Households are the big losers in our climate scenario, especially female-headed households, due to their strong presence in traditional agricultural activities, which suffer the most from climate damage. Moreover, with declining employment and rising food prices, food poverty increases mainly in female-headed households. In addition, we found an interesting association between vulnerability according to the location of the household and the gender of the household head. On the one hand, the consumption of traditional agricultural products sees the greatest decline and is higher in female-headed households, with those in the highland and valley regions being the most affected. On the other hand, the increase in food poverty, which affects women more than men, is particularly higher for highland women. These results could affect the food security of Bolivia's most vulnerable citizens, particularly women, since the consumption of traditional foods such as cereals, vegetables and fruit constitutes an important part of their daily diet.

The main contribution of this study is to link the impacts of climate disasters, gender and food security. However, it also has several limitations that offer opportunities for future research. First, the design of our climate disaster scenario only refers to the analysis of destructive events experienced by Bolivia in 2013–2014. Future studies could extend and make a more general analysis of the impact of climate disasters in this country, considering natural origins such as El Niño and La Niña and human-induced disasters such as fires. Second, the ex post framework adopted in this study is important to analyse specific phenomena in a particular period and to understand the first- and second-order effects on the whole economy. However, it is noteworthy that although Bolivia is characterised as a country that is frequently affected

by climatic disasters, the intensity with which they occur is not the same and has varied considerably over the years. In this sense, integrating aspects such as the probabilities of occurrence of specific phenomena, considering the history of disasters that have occurred in this country in the past, would be relevant, especially in the framework of ex ante prevention studies. Third, it should also be considered that the government response to climate disasters tends to be immediate or short-term. In this study, we do not consider responses to disasters or the analysis of any adaptation or reconstruction policies. These policies should be analysed in future studies to provide more far-reaching policy implications. Finally, we should note that our study was conducted in Bolivia, a country that shares some characteristics with other developing countries but is also unique in some contextual elements that provide information for advancing the theory. In this sense, future research could be directed towards exploring the effects of climate disasters in other developing countries, mainly in Latin America, as they share similar socioeconomic characteristics. This would allow us to determine to what extent our findings are different from those in other contexts. Moreover, the results may also be useful to guide the adoption of adaptation.

Despite these limitations, the findings of this study provide strong evidence that climate disasters are undermining Bolivia's food security and are affecting men and women differently, depending on their regional location. Although there is some uncertainty about the magnitude of the effects of climate disasters, our results can be contrasted by the negative trend observed at the food level, especially during the period of climate disasters (2013–2014). The development of the Bolivian agroindustry between 1998 and 2017 has been important but has had an uneven and inefficient influence on food availability (Rodríguez Mendez et al., 2019). Moreover, FAO indicators related to economic and political stability, such as the variability of per capita food production or variability of per capita food supply, show no improvement and even register drastic drops during the period of climate disasters (2013–2014). The same has happened for the average value of food production, which, despite constant increases in cereal and animal protein production, has not stopped its downward trend since 2014 (FAOSTAT, 2020).

One key finding from a policy intervention point of view is that increases in food insecurity and food poverty due to climate disasters are not uniform across skill levels, location and gender. Here, low-skilled workers and women in the highland regions suffer the most. This suggests that in developing reconstruction and climate adaptation strategies, the Bolivian

government should promote sector-specific investments and actions that benefit the most vulnerable people. In particular, our results support the following policy recommendations.

- A policy of expanding public investment to recover damaged infrastructure, mainly in the traditional agricultural sector, could partially reverse sectoral losses and improve the availability of foodstuffs essential to ensure food security.
- Promoting local market sales to increase the availability of local food, particularly in the lowland region, and staple food products should be a priority in the policy agenda accompanying the economic recovery after a climate disaster.
- Measures to diversify agricultural production are needed to avoid dependence on a few commodities such as soybeans. Policy options could include broadening the agricultural export basket by seeking a greater diversity of modern products and increasing the share of traditional products.
- Region-specific support packages, particularly for women in the highland region, can be effective in increasing purchasing power, reducing the risk of food insecurity and curbing the increase in food poverty.
- The participation of less-skilled Bolivian women in other economic sectors should be promoted, as their concentration in traditional agricultural sectors highly exposed to climate disasters makes them more vulnerable.

Chapitre 3

III. Climate Disasters, Women and Poverty: Towards Inclusive Disaster Risk Reduction in Bolivia

Abstract: In recent years, climate disasters have become increasingly visible around the world, affecting economic sectors and populations. However, the effects on specific issues, such as the labour market and gender, remain to some extent unknown. Taking as a case study the damages recorded in Bolivia between 2013 and 2014 due to climate disasters, this paper uses a dynamic gender-sensitive computable general equilibrium model (CGE) with microsimulation to analyse the ex-post impact of climate disasters and reconstruction on the labour market and poverty from a gender perspective. The results reveal that disaster damage has negative effects on the economy, while investment in reconstruction has positive effects. However, there are no clear improvements in reducing gender gaps that remain even with reconstruction. Indeed, we found that income poverty and food poverty are reduced with investment policies, but these remain higher among women, mainly in rural areas. In the labour market, disasters lead to job destruction for all workers, while investment in reconstruction leads to job creation, favouring slightly more the employment of unskilled and semi-skilled workers.

Keywords: Climate disasters, General equilibrium model, Gender, Reconstruction, Poverty

JEL: Q54, C68, J16, O54

3.1.Introduction

The global effects of climate disasters in the coming decades are already a certainty. According to the Intergovernmental Panel on Climate Change (IPCC), natural disasters will become even more recurrent and intense due to the increased concentration of greenhouse gases in the atmosphere (IPCC, 2012). Furthermore, the IPCC highlighted that climate-related risks are very unevenly distributed and are generally higher for developing countries (Field et al., 2014).

In recent years, academic and policy discussions have increasingly focused on the analysis of climate disasters in multiple dimensions and economic sectors, considering aspects such as poverty and vulnerability. The IPCC revived a global effort to counteract climate change-related effects by taking into account socioeconomic aspects, and called for an analysis of the impacts on vulnerable socioeconomic groups (IPCC 2014, 2018). Groeschl and Noy (2020), recently called for a more systematic investigation of the links between climate change, natural disaster frequency and socioeconomic vulnerability. Among the most vulnerable population groups in developing countries, evidence suggests that women are the most affected (Björnberg & Hansson, 2013; Denton, 2002; Goh, 2012; Quisumbing et al., 2018). According to (Alam et al., 2015), The impacts of drought, floods, extreme weather, increased incidence of disease, and growing food and water insecurity disproportionately affect the world's 1.3 billion poor, the majority of whom are women.

While regional and global studies are important for understanding the scope and scale of problems associated with climate disasters, mainly in developing countries, specific (country-level) studies are able to provide more in-depth analysis. In this paper, we consider this country-specific approach and propose a study focusing on Bolivia. Located in the geographical heart of South America, Bolivia is a landlocked country in the centre-west of the continent. The interest in this country lies in the fact that it is considered the second most affected South American country by extreme weather events. In 2014, Bolivia ranked eighth in the worldwide top 10 list of countries affected by such phenomena (Kreft et al., 2016). Exposure to extreme natural events in recent years has shown increasingly devastating effects on the whole economy and this is partly explained by climate change related effects. Indeed, the high vulnerability of this country is explained by a significant increase in the number and intensity of adverse natural events related to climate change (García del Castillo & Naranjo Mejía, 2016; Jaramillo, 2009).

In this country, floods and droughts have historically been the most frequent disasters. However, in recent years, and especially since 2015, the number of fires has increased dramatically, and today they are also one of the country's biggest environmental problems (VIDECI, 2018). In this context of high exposure to these climatic phenomena in Bolivia, the main objective of this study is to model, on the one hand, the short- and long-term impacts of climate disasters and, on the other hand, the reconstruction investment involved in post-disaster recovery. For this, we will use as a case study the disasters reported between 2013 and 2014 in the Bolivian territory, and in terms of the post-disaster reconstruction investment scenario, we will focus on the investments made in the framework of the declarations of state of emergency and the investments in reconstruction that were made in the framework of the " Patujú" plan. The latter is a comprehensive reconstruction and recovery plan that Bolivia launched to help areas affected by disasters, including prevention and risk reduction measures.

In addition, following the suggestions of the IPCC, and the evidence observed in different developing countries around the world, in this study we will also be particularly interested in analysing the impact of climate disasters on vulnerable populations and their welfare in terms of consumption and poverty. In section 3.2 we present the importance of targeting these populations in Bolivia mainly in a context of high exposure to climate disasters. In particular, we will consider several factors such as geographical location (rural, urban), the qualification levels of workers (skilled, semi-skilled and unskilled) and gender (men and women). These are aspects that influence and condition the vulnerability of Bolivians.

How do climate disasters affect the welfare of men and women in rural and urban Bolivia in the long run? Are gender gaps in poverty and the labour market widening with climate disasters? What policies should be adopted to achieve an inclusive reduction of climate disaster-induced risks? These are some of the questions that motivated this research and will be answered throughout the paper.

To answer these research questions, we constructed a Macro-Micro which has a sequential resolution in two steps. In a first stage, we developed a dynamic recursive gender - sensitive Computable General Equilibrium (CGE). This is an appropriate approach for this study as it allows modelling both disasters impact and reconstruction investment in a long-term, unified framework. In addition, we present a gender-sensitive CGE to focus particularly on the effects on women. In a second stage of resolution, we draw on some results from the CGE to feed a microsimulation module that will allow us to deepen the analysis and assess the distributional impacts on women's poverty.

There is a growing literature of CGE studies related to climate disaster assessment (Kajitani & Tatano, 2018; Koks et al., 2016; Koks & Thissen, 2016; Wu & Guo, 2021). Most of these suggest that the destruction caused by these climate shocks generates substantial economic losses. In the specific case of Bolivia, the vast majority of CGE studies adopt a deterministic approach to study conditions more related to long-term climate change than to climate disasters, and focus especially on the agricultural sectors (Andersen et al., 2014; Calvo, 2014; Jemio et al., 2014; F. Viscarra, 2014; F. E. Viscarra et al., 2018). Arenas (2005, 2009), develops a CGE to address the effects of extreme events, in particular El Niño and La Niña during the years 2006-2008. The author indicates that climate shocks will have a strong impact on public infrastructure and agricultural production at the end of the 21st century. However, the latter and most studies on CGE in the literature in general have overlooked the interconnections with dimensions such as poverty and specific impacts on vulnerable groups, such as women in rural areas.

This research is innovative from three points of view: First, this work contributes to the development of dynamic CGE models related to disasters by introducing a gender approach that captures differentiated effects for men and women. Second, a top-down gender approach is also introduced through the micro module to analyse the long-term impact on women's poverty. Third, our modelling approach proposes a unified framework for analysing the adoption of investment policies in post-disaster reconstruction. In summary, these three points represent an interesting contribution for both academics and policy analysts in a country where there are few comprehensive macroeconomic studies on the effects of climate disasters.

The following parts of this paper are organized in five sections covering topics related to an overview of the connections between poverty, gender and climate disasters in Bolivia (section 2), the presentation of the main data and the methodology used in the study (section 3), the presentation of the climate disaster scenario and the main results and impacts on the Bolivian economy and particularly on women (section 4). Finally, the research concludes with section 5, which offers some general conclusions and specific recommendations in the search for an inclusive disaster risk reduction in Bolivia.

3.2. Overview of linkages between poverty, gender and climate disasters in Bolivia

In recent years, Bolivia has made undeniable progress in reducing poverty from 60% in 2000 to 37% in 2019 (WDI, 2019). However, reductions have not been regular across the territory. In 2019, poverty in urban areas reached 31%, while in rural areas 51% of the population lives in poverty. Within these areas, women are the most affected, with rates reaching 52.3% (INE, 2019). These trends reveal the existence of gender gaps, where the rural population and particularly rural women appear to be the most exposed to poverty.

Gender inequality also extends to the labour market, where gender roles are relatively well defined. The Bolivian labour market is characterised by a substantially lower participation of women compared to men. In 2019, the employment participation rate for men reached 80%, compared to 64% for women (ILOSTAT, 2019). Moreover, Bolivian women work in a narrow range of sectors. Female labour intensity is in fact present in only 7 of the 21 economic sectors registered in the national employment survey. Among the most female labour-intensive sectors, accommodation and food services, education, health and social services and private domestic activities stand out (INE, 2018). In rural areas, role differences are even more pronounced as men tend to be responsible for physical labour in the agricultural sector and high-value economic activities (mining, timber, transport services and migrant or wage labour), while women are responsible for supporting men in the productive sectors, subsistence farming and other small-scale income-generating activities such as handicraft production and beekeeping (Ashwill et al., 2011). Consequently, gender roles and gender gaps in the labour market are visible and reveal that women tend to participate much less than men and tend to perform jobs that are less valued in economic terms, mainly in rural areas.

This already delicate situation of women, mainly in rural areas, could be aggravated and become even more critical in a context of high vulnerability to disasters. Indeed, the linkages between climate disasters and gender dynamics can be observed in the "exposure" to disasters and in the "impacts" of disasters. In Bolivia, the extreme topography, high biodiversity and cultural heterogeneity impose very specific climatic impacts throughout the country (Ashwill et al., 2011). (J. Arenas, 2009), indicates that Bolivia is associated with a variety of natural disasters, including floods in the departments located in the Amazon zone, droughts in the Chaco zone, and fierce hailstorms in the Altiplano.

The impacts of climate disasters are thus regionally and departmentally unequal, but they are also unequal between men and women. According to a study based on the natural

disasters caused by the 2008 La Niña phenomenon, the effects on women were greater than on men, especially in rural areas ((MPD & CEPAL, 2008).

Table 3.1: Economic impact on women of floods, frosts and hailstorms caused by La Niña, 2008

Region	Department	Number of women affected	Women affected (in %)	Rural women affected (in %)	Damage to agricultural production	Damage to agricultural production* (in %)
Highlands	La Paz	48883	22,4	32,9	20485516	17,6
	Oruro	56906	26,0	38,4	27841987	23,9
	Potosi	6658	3,0	65,7	5578238	4,8
Valleys	Chuquisaca	74341	34,0	57,9	50483235	43,3
	Tarija	29268	13,4	34,8	11952231	10,2
Lowlands	Pando	2456	1,1	57,7	363719	0,3
Total		218512			116704925	

* These are crops. Includes market and subsistence production destroyed by floods, frosts and hailstorms. Estimated 2375 Bol for each woman farmer.

Source: Authors' elaboration based on (MPD & CEPAL, 2008)

As can be seen in Table 3.1, the highlands region registers the highest number of women affected by disasters in 2008, with women in rural areas being the hardest hit. In the valleys region, the agricultural damage are mainly concentrated in the department of Chuquisaca, where about 60% of rural women were affected. Finally, in the lowlands region, women and agriculture were less affected overall. Therefore, the impact of disasters is intertwined with gender gaps, as past experiences reveal that Bolivian women are the most vulnerable when climate disasters occur.

Another key aspect to take into account is the gender gap in educational attainment. This is particularly important as the largest gaps appear in the labour market, and this could be explained by differences in education levels that somehow condition access to the labour market. According to INEI, (2019), education levels are lower overall in rural areas, with Bolivian women having the lowest levels of qualifications.

Therefore, in a context of high exposure to natural disasters, it is essential to integrate aspects such as labour market gaps by skill level, rural-urban gaps, gender gaps, and possible interconnections with poverty.

3.3.Data and Methodological framework

Following a top-down approach to assess the long-run impacts of climate disasters on economic sectors and particularly on women in Bolivia, this study develops a Macro-Micro model that includes two main stages. In a first stage, we build a dynamic and recursive gender-sensitive CGE model, and in a second stage, we couple the CGE model to a micro-simulation module in order to assess the redistributive effects on poverty. The following are the main data requirements and the main characteristics of the model.

3.3.1. Data

The model implemented in this study contains 20 sectors and 30 products. As indicated at the beginning of the section, we present a top-down model. As indicated at the beginning of the section, we present a top-down model starting with a CGE Macro model. An important part of the data processed by the CGE was obtained from the 2012 Social Accounting Matrix (SAM) for Bolivia, derived from the IFPRI et al. (2015). Also, several elasticity parameters are taken from the literature. This is the case of household income elasticities taken from Morales et al.2017. Similarly, the transformation elasticities between export and domestic production, as well as the elasticities in the Armington functions of the import and production blocks are based on Sevillano Cordero (2012). Finally, the elasticities of substitution in the labour market, and particularly between men and women are based on previous studies that consider gendered approaches to labour market modelling (Fofana,fontana, 2000).

In terms of the shocks required for the scenario design, disaster damage comes from the damage and loss report prepared by UDAPE, (2015). While data on reconstruction investments come from nine national decrees implemented between 2014 and 2016 on reconstruction investments in the framework of the Patujú plan (see Tables 3.3 and 3.4 for a more detailed description of the data and information used to design the shocks).

Finally, the main source of data for the microsimulation module comes from the National Household Survey (2019).

3.3.2. The Macro-Micro model

3.3.2.1. The dynamic recursive CGE model

Climate catastrophes are often associated with negative effects at a specific point in time; however, economic sectors and, in particular, households can recover to some extent once the climate shock has passed, so a dynamic CGE model is ideal for our modelling framework as it allows us to introduce direct disaster shocks in year T1, and then allows us to consider second-order effects in the remaining periods. Moreover, we use a CGE model because it allows us to measure the intersectoral effects between agricultural and non-agricultural sectors as well as on economic agents, especially women. Our model is based on the PEP model (1-t) from (Decaluwe et al., 2013). It is a dynamic and recursive CGE model that incorporates classical general equilibrium features. In the following, we briefly describe the main characteristics of the standard model and the main modifications introduced to it.

The model stipulates that production is characterised by a multilevel function. At the top-level production follows a Leontief-type function between value added and intermediate consumption; with this we assume that production is a fixed part of intermediate consumption and value added for each economic sector. On a second level, value added is defined using a constant elasticity of substitution (CES) function between composite labour and capital. This means that each sector combines labour and capital to create their production. In the standard model, these composite labour and capital functions are written in a general form. However, in order to represent, as realistic as possible, the characteristics and specifications of the Bolivian economy, we opted for including a detailed disaggregation of labour.

To this end, we modify the general assumptions of the basic model in order to introduce a breakdown by skill level and gender in the labour market. This breakdown is relevant for Bolivia, as there are significant differences in sectoral labour intensities by gender and skill level. Moreover, as indicated in the introduction, Bolivia still has important gender gaps in education that often condition the type of employment and access to employment. Based on these considerations, and in contrast to the standard model, we model each industry of demand for composite labour (LDC_j) through a CES function between three different skill levels: demand for skilled workers (LQ_j), demand for semi-skilled workers (LMQ_j), and demand for unskilled workers (LNQ_j). Each of these labour demands are calibrated with parameters of scale (B_j^{LD}) and proportion ($\alpha_j^{LD}, \beta_j^{LD}$), and are influenced by an elasticity parameter (ρ_j^{LD}) that

define the ease and/or difficulty of substitution among workers (equation 1). It is worth noting that low elasticities of substitution are used to account for some degree of substitution difficulty among workers, especially for semi-skilled and unskilled workers.

$$(1) LDC_j = B_j^{LD} \left[\alpha_j^{LD} LQ_j^{-\rho_j^{LD}} + \beta_j^{LD} LMQ_j^{-\rho_j^{LD}} + (1 - \alpha_j^{LD} - \beta_j^{LD}) LNQ_j^{-\rho_j^{LD}} \right]^{-1/\rho_j^{LD}}$$

Secondly, we extend the CES functions within each skill level by considering male and female workers as imperfect substitutes. This implies that male and female labour can be substituted in the model if and only if their skill level is the same, which is in agreement with the reality of the labour market in Bolivia. Moreover, to represent the gender bias observed in the Bolivian labour market, we use low values for the elasticities of substitution that assume that men and women are not easily substitutable. Equations 2 to 4 describe this process for skilled workers (equation 2), semi-skilled workers (equation 3) and unskilled workers (equation 4).

$$(2) LQ_j = B_j^{LQ} \left[\beta_j^{LQ} LHQ_j^{-\rho_j^{LQ}} + (1 - \beta_j^{LQ}) LFQ_j^{-\rho_j^{LQ}} \right]^{-1/\rho_j^{LQ}}$$

$$(3) LMQ_j = B_j^{LMQ} \left[\beta_j^{LMQ} LHMQ_j^{-\rho_j^{LMQ}} + (1 - \beta_j^{LMQ}) LFMQ_j^{-\rho_j^{LMQ}} \right]^{-1/\rho_j^{LMQ}}$$

$$(4) LNQ_j = B_j^{LNQ} \left[\beta_j^{LNQ} LHNQ_j^{-\rho_j^{LNQ}} + (1 - \beta_j^{LNQ}) LFNQ_j^{-\rho_j^{LNQ}} \right]^{-1/\rho_j^{LNQ}}$$

With:

$B_j^{LQ}, B_j^{LMQ}, B_j^{LNQ}$: Scale parameters for Skilled, semi-skilled and unskilled labour, respectively

$\beta_j^{LQ}, \beta_j^{LMQ}, \beta_j^{LNQ}$: Share parameters for Skilled, semi-skilled and unskilled labour, respectively

$\rho_j^{LQ}, \rho_j^{LMQ}, \rho_j^{LNQ}$: Elasticity parameters for Skilled, semi-skilled and unskilled labour, respectively

LHQ_j and LFQ_j : Labour demand for male and female skilled workers

$LHMQ_j$ and $LFMQ_j$: Labour demand for male and female semi-skilled workers

$LHNQ_j$ and $LFNQ_j$: Labour demand for male and female unskilled workers

3.3.2.2. Institutions in the CGE Model

The model distinguishes four different institutions: households, firms, the government and the rest of the world. Households are also disaggregated by gender (male- and female-headed households) and location (rural and urban areas) creating four categories of representative households. In the following, we present the main characteristics of economic institutions and their specifications.

Table 3.2: Source of household's income by gender and location (in %)

	Source of household's income								
	Labour income				Land	Transfers income			
	Skilled	Semi-skilled	Non-skilled	Total Labour	income	FIRM	GVT	ROW	Total Transfers
Rural male	0,36	0,40	0,12	0,89	0,01	0,03	0,03	0,05	0,10
Rural female	0,34	0,33	0,10	0,77	0,01	0,02	0,07	0,13	0,22
Urban male	0,13	0,40	0,31	0,84	0,03	0,04	0,05	0,04	0,13
Urban female	0,12	0,36	0,26	0,75	0,02	0,04	0,09	0,10	0,23

Source: Own elaboration based on the Social Accounting Matrix, 2012

Note: FIRM = Companies, GVT = Government, ROW = Rest of the world

As we can see in table 3.2, the model distinguishes three different sources of income for households: labour income, land income and transfers from other agents. The income of male-headed households comes mainly from labour in both rural (89%) and urban (84%) areas. In female-headed households, income from labour is also the main source of revenue, but to a lesser extent than that of male-headed households. (77% and 75% in both rural and urban areas respectively). Furthermore, across all household categories, semi-skilled labour is the largest contributor to income, particularly in male-headed households where it accounts for 40% of total income. Income from transfers from other institutions also constitutes an important part of household income (between 10% and 23%). This source of income is particularly important for female-headed households, where it reaches more than 20% of their total income in both rural and urban areas, compared to 10% and 13% for male-headed households in rural and urban areas respectively. Finally, households receive income from land. Although this source accounts for the smallest share of total income (1% to 3%), it should be noted that it is proportionally higher in male-headed households. Moreover, urban households receive the biggest share of land rent (more than 90% of this income is earned by urban households).

All categories of households use their income for tax payments, savings and, above all, final consumption. The propensity to consume is higher in male-headed households, which spend 89% of their income compared to 87% of their female counterparts. Moreover, rural households spend a larger proportion of their income on consumption compared to urban ones (92% vs 88%). As for savings, they represent between 8% and 13% of total household income and the largest contribution to savings is made by urban households (12.4% in male-headed households, 12.7% in female-headed households).

The Government collects direct taxes from domestic institutions, import duties, and indirect taxes (taxes on commodities and taxes on production). Indirect taxes provide the bulk of government revenue (more than 50%). Government resources are spent on public spending, mainly on non-tradable public services (44%), and on transfers to other economic agents (17%). Firms' income is based mainly on capital income (96%) and transfers from the government (4%). They pay dividends to households, income taxes, transfers to other institutions, and the remaining income constitutes the firms' savings.

In order to model transfers as neutrally as possible, we assume that transfers from the government and the rest of the world are fixed at their initial values and indexed with the consumer price index (see Decaluwé et al. 2013), while transfers from firms are modelled as a share of firms' disposable income.

3.3.2.3. Modelling of climate disasters and reconstruction investment the CGE model

As for the modelling of climate disasters, these are introduced into the model in the year in which the disasters were reported, we assume that the disasters caused a decline in the capital stock in various industries (damage). The estimation of these damages is based on the UDAPE (2015) report, which values the production losses between 2013 and 2014 due to adverse phenomena across the country. Table 3.3 summarises the set of these damages at the sectoral level.

Table 3.3: Direct and indirect economic losses due to climatic disasters by sectors between 2013 and 2014 (Millions of Bolivianos)

Sector	Loss
Agriculture (Highlands)	152.61
Agriculture (Valleys)	545.75
Agriculture (Lowlands)	350.59
AGRICULTURE	1048.95
Transport	491.69
Water and sanitation	102.28
Electricity	7.54
Telecommunications	2.79
Forestry and fishing	37.40
Health and social	91.39
Housing/construction	230.35
TOTAL NON-FARM SECTOR	963.44

Source: Authors' elaboration, based on UDAPE (2015).

To implement this shock in the model, we create the DAMAG variable, which is initialised to zero and fixed. This variable represents climate damage to the capital stock and thus negatively influences the capital accumulation equation of the sectors affected by disasters (see equation 5).

In addition, regarding the modelling of post-disaster investments, and taking into account the fact that reconstruction by investment that restores the capital stock due to disasters is faster than in normal circumstances, we model part of the reconstruction investment in the first year, and the rest in the years following the disasters. This modelling framework is supported by the state of emergency supreme decrees that were issued during 2014 and authorised immediate extra-budgetary expenditures. Specifically, we consider the Supreme Decree N° 2128, which authorised the purchase of raw materials, processing and replacement or refurbishment of production infrastructure for an amount of 73.66 million bolivianos (bs). Likewise, we consider the Supreme Decree No. 1957, which authorised the transfer of resources from the General Treasury of the Nation (TGN for its acronym in Spanish), to the Agency for the Development of Macro-regions and Border Zones (ADEMAF for its acronym in Spanish),

to concurrently finance the rehabilitation and construction of deflectors and defences, as well as the replacement and improvement of infrastructure for an amount of 140 million bolivianos (bs). Technically, to estimate this compensation factor in the first year, we assume that a part of the total investment will form the capital stock in the first year. This amount is earmarked for reconstruction in the construction, transport and agricultural sectors.

The remaining reconstruction investments are introduced in the three years following the occurrence of disasters. These investments are based on the budget allocated to integrated actions such as the repair and recovery of infrastructure in the transport, basic services and construction sectors within the framework of the " Patujú " Plan. This recovery and prevention plan has a total investment of US\$476 million (3301 million Bolivianos) from the state, through the approval of nine supreme decrees and two resolutions. Of the US\$476 million, US\$246 million was allocated to infrastructure affected mainly by flooding and US\$230 million to road construction and rehabilitation. Table 3.4 summarises the investment shocks under the emergency decrees and the “Patujú” plan designed to counteract the impacts of disasters.

Table 3.4: Reconstruction investments supported by government over the 3 years after the climate disasters (Millions of Bolivianos)

	T0	T1	T2	T3	TOTAL
Productive infrastructure (agricultural sector)	73.66				73.66
Improvement of infrastructure and construction (Construction)	140				140.00
Plan Patujú		1100.4	1100.4	1100.4	3301.08

Source: Authors' elaboration

To implement both disaster shock and investment shocks in an integrated framework, it is necessary to disaggregate the capital accumulation equation into 2 sub-equations (equations 5 and 6). Equation 5 represents the capital stock of the sectors affected by disasters and receiving reconstruction investment. Equation 6 in turn represents the capital stock of the other sectors and is maintained as in the base model. This breakdown allows for specific changes in each equation. Thus, the equations for the capital stock in the sectors receiving investment (construction, transport and agriculture) were augmented with new public reconstruction investment ($IND_DAM_{k,dam,t-1}$), while the equation for the capital stock of the remaining sectors remained similar to the base model (see equation 6).

$$(5) \quad KD_{k,dam,t} = KD_{k,dam,t-1} * (1 - \delta_{k,dam,t}) + IND_{k,dam,t-1} - DAMAG_{k,dam,t-1} + IND_DAM_{k,dam,t-1}$$

$$(6) \quad KD_{k,ndam,t} = KD_{k,ndam,t-1} * (1 - \delta_{k,ndam,t}) + IND_{k,ndam,t-1}$$

Where:

$KD_{k,dam,t}$ and $KD_{k,ndam,t}$: Demand for capital in period t (affected and non-affected industries)

$KD_{k,dam,t-1}$ and $KD_{k,ndam,t-1}$: Demand for capital in period t-1 (affected and non-affected industries)

$\delta_{k,dam,t}$ and $\delta_{k,ndam,t}$: Capital depreciation rate (affected and non-affected industries)

$IND_{k,dam,t-1}$ and $IND_{k,ndam,t-1}$: Private and public investments in t - 1 (affected and non-affected industries)

$IND_DAM_{k,dam,t-1}$: New public reconstruction investment.

$DAMAG_{k,dam,t-1}$: Climate damage to the capital stock in period t-1

3.3.2.4. Closure rules

As for the financing policy for new reconstruction investments, we opted for the use of public deficit to finance these investments. This policy has been widely used over the last few years. In fact, since 2014, the Bolivian government has been spending more money than it generates and going further and further into public deficit to cover its budget, which is reflected in a World Bank (WB) report that forecasts that the country's total consolidated debt this year will represent close to 80% of GDP in 2022 (World Bank, 2022). It is worth noting that this percentage is well above the regional average in Latin America and the Caribbean (69.8%).

Therefore, to model this type of financing, in the model closure, we start with the assumption that public expenditure is considered fixed in the base year, while savings is an endogenous variable. As for the rest of the closure rules of the CGE model, all tax rates (direct, indirect, import, production) are fixed. Transfers between institutions are fixed in the base year and then grow at the rate of population. We also assume that Bolivia is a small "price taker" economy in global export and import markets since it produces a very small percentage of world output and has no influence on the evolution of world prices, which are therefore considered exogenous. In the labour market, capital and labour are mobile across sectors, which characterises a long-run assumption. Finally, the nominal exchange rate is taken as the numeraire of the model.

3.3.2.5. Microsimulation module

To assess distributional impacts, we link the CGE model to a microeconomic analysis module. This analysis is based on the calculation of the FGT indicators of Foster et al. (1984). Technically, once the first resolution is carried out in the CGE framework, outputs such as changes in the wage rate, the level of income and prices are taken and fed into the micro module. This module allows us to carry out our second resolution which aims to deepen the analysis to estimate changes in poverty in rural and urban areas, and for both men and women.

3.4. Scenarios and results

3.4.1. Scenarios

Two scenarios were constructed and compared in this study; a disaster scenario without reconstruction investment, in which the capital stock was reduced due to the disaster and there was a normal investment but no reconstruction investment (S1); and a disaster scenario with reconstruction in which the capital stock was reduced due to the disaster and there was normal investment and reconstruction investment (S2).

As for the catastrophe scenario, as indicated in section 3.3.2.3, this is based on the (UDAPE, 2015) report which estimates the economic losses due to climate disasters that occurred between 2013 and 2014. It considers sectoral capital loss for agricultural and non-agricultural sectors (e.g., machineries, factories, roads, infrastructure) suffered in Bolivia by climatic events. Specifically, the simulation considers disaster-related losses in the agricultural sector at 1048.95 million Bolivianos, and losses in the non-agricultural sectors at 963.44 million Bolivianos (See table 3.4).

Results and discussion

3.4.2. Macro results

Overall, the results reveal that the economic losses in the simulation without reconstruction investment policy (S1) are approximately 0.5 percentage points higher than in the scenario with reconstruction (S2). It is worth noting that the S2 results are closer to the real data since in the case of Bolivia they reflect a fall in public savings due to the extra-budgetary expenditures involved in disaster response.

As expected, the results of the climate disasters (S1) have a negative impact on the economy as a whole and particularly on the agricultural sectors that suffer the most damage. This trend is ultimately reflected in detrimental effects on macroeconomic indicators in the short and long term (see table 3.5). Overall, output falls in both agricultural and non-agricultural sectors. Wages fall substantially, food prices rise slightly in the short term due to disaster-induced commodity shortages, and household consumption is affected, mainly in the short term.

In both scenarios, the results are less damaging in the long run as the direct shock is only introduced in the first year. Moreover, when investment in reconstruction (S2) is added, the impacts on these macroeconomic variables are even less unfavourable, we can therefore conclude that the effects of this economic policy with deficit-based financing have been essentially positive at a macroeconomic level.

Table 3.5: Macro Results in the short and long run (% change)

Item	Climate disasters without reconstruction (S1)		Climate disasters with reconstruction (S2)	
	Short run	Long run	Short run	Long Run
Real GDP at basic prices	-2.49	-0.59	-2.16	-0.40
Consumer price index	0.25	-0.48	0.15	-0.38
Real consumption budget of households	-8.60	-1.90	-7.40	-1.60
Aggregate agricultural production	-9.32	-2,40	-6.51	-2.05
Aggregate non-agricultural production	-1.52	-1.05	-1.65	-0.09
Wage rate (Composite labour)	-13.77	-2.94	-11.59	-2.47

Source: Calculations based on the CGE model

3.4.3. Sectoral results

The results of the disaster simulation without reconstruction (S1) reveal a decline in output for almost all sectors, both in the short and long term. With investment in reconstruction (S2), the negative trend improves and shows milder declines, with 5 sectors benefiting from increases in output. Among the sectors that benefited the most are the construction sector, agriculture in the highland region, and mining. This is explained by the fact that these three sectors are the largest recipients of investment, and in the case of the construction sector, the latter benefits directly from new investment flow from the state to counteract the destruction caused by disasters.

Output decreases in most sectors, and particularly in two agricultural sectors (lowlands and valleys). The particularly negative effect in these agricultural sectors is explained by their high capital use which is directly affected in the disaster simulation scenario. In contrast, in the highlands region agriculture is more labour intensive, which explains why it is not affected as much. In all other non-agricultural sectors the effect is negative overall except for construction, mining and the public sector. Consequently, the negative trend in output produces negative effects on sectoral employment. Indeed, in the first scenario, the destruction of disasters produces a fall in agricultural employment of 7.3% in the short term and 0.42% in the long term, while employment in non-agricultural sectors registers a slight fall of 0.09% in the short term and an increase of 0.05% in the long term. When reconstruction (S2) is added, the results at the production and employment level are less negative, particularly for the non-agricultural sectors which register an increase of 0.51% in the short run, and 0.04% in the long run.

Table 3.6: Sectoral employment effects

	Climate disasters without reconstruction (S1)		Climate disasters with reconstruction (S2)	
	Short run	Long run	Short run	Long Run
Agriculture - Highlands	-3,26%	5,42%	5,58%	7,38%
Agriculture - Valleys	-19,41%	-6,50%	-15,32%	-7,97%
Agriculture - Lowlands	0,31%	-3,36%	-1,36%	-2,62%
Forestry & fishing	-0,86%	-0,20%	-0,66%	-0,14%
Hydrocarbons	1,93%	-1,18%	1,10%	-1,09%
Mining	5,46%	1,82%	4,17%	1,61%
Food processing	-8,95%	-1,41%	-6,17%	-1,24%
Beverages and tobacco	-2,31%	-1,44%	-2,42%	-1,23%
Textiles	1,74%	-0,37%	0,95%	-0,33%
Paper and wood	-2,05%	-0,37%	-2,24%	-0,31%
Refined oil products	0,49%	-0,29%	-0,03%	-0,28%
Machinery and metal products	5,30%	1,62%	3,83%	1,42%
Electricity gas and water	-6,45%	-1,17%	-6,70%	-1,00%
Construction	-0,94%	1,74%	-0,40%	1,54%
Commerce	-2,88%	-0,70%	-2,07%	-0,59%
Transportation	-4,04%	-1,12%	-3,88%	-0,96%
Financial services	-0,87%	-1,01%	-1,11%	-0,85%
Social services	-3,89%	-0,91%	-3,85%	-0,77%
Restaurants & hotels	-0,93%	-2,04%	-1,25%	-1,77%
Public administration	7,89%	1,53%	6,47%	1,28%

Source: Calculations based on the CGE model

However, when looking at the disaggregated sectoral effects, the employment gains benefit from only five economic sectors: agriculture in the highlands region, construction, mining, machinery and the public sector. Table 3.6 shows the employment effects at sectoral level in both the short and long term. The outflow of workers, mainly in most economic sectors and particularly in the agricultural sectors (lowlands and valleys), translates into a decrease in wage rates, and thus in household incomes. Moreover, since labour is their main source of income (see table 3.2), this could eventually affect total household revenues and compromise their welfare.

3.4.4. Gendered impacts

Although workers and mainly those linked to agricultural employment are the most affected, they are not affected in the same proportions according to gender and level of education. Overall, women are slightly more affected, and mainly skilled women, who are present in capital-intensive agricultural sectors, whose production suffers significant losses.

Analyses of the first simulation reveal that female agricultural employment declines by around 6% in the short term for all employment categories, with semi-skilled women being the most affected. With the reconstruction policy (simulation 2), agricultural employment falls by less than 3%. This means that the reconstruction policy ultimately favours job creation for women. Moreover, low-skilled workers benefit the most from job creation since the reconstruction investment falls on the construction and transport sectors which are most intensive in unskilled and semi-skilled labour. However, compared to men, increases in women's employment due to reconstruction are smaller in proportion, suggesting that investment in reconstruction does not lead to a narrowing of gender gaps.

Wage declines, and reductions in female employment, particularly in the first simulation, substantially affect household labour income, which is the main source of income. As a result, in the short run income falls by about 9% in the first simulation versus 7% in the second, with rural women being the most affected. This is explained by the fact that in rural areas women tend to be more involved in agricultural activities, which suffer most of the damage due to climate disasters and record the largest drops in employment. This trend is also observed in the long term, although with much milder impacts.

On the consumption side, as the price index increases slightly in the short term, the impacts are also negative for households (see table 3.5). However, these impacts are not

uniform across rural and urban areas. Thus, in the short run, the first simulation leads to a reduction of women's consumption by 9% and 8% in rural and urban areas. In the long term, the falls are smaller but remain larger for rural women compared to their urban counterparts (1.8% vs. 1.6%).

The impacts on the consumption of agricultural goods are particularly important as they register significant falls. As can be seen in table 3.7, rural women are once again the ones who see the most drastic drops. The second simulation improves the situation for both men and women, mainly in the long run, with urban men benefiting the most as they register an increase in consumption of agricultural goods of 0.78%.

Table 3.7: Impacts on consumption of agricultural goods by gender and location

	Climate disasters without reconstruction (S1)		Climate disasters with reconstruction (S2)	
	Short run	Long run	Short run	Long Run
Rural male	-18,66%	-1,34%	-12,57%	-0,66%
Rural female	-19,26%	-1,44%	-12,32%	-0,63%
Urban male	-17,41%	-0,99%	-11,63%	0,78%
Urban female	-16,73%	-0,62%	-10,79%	-0,47%

Source: Calculations based on the CGE model

3.4.5. Impacts on Poverty

To assess the impact of climatic shocks on the evolution of poverty, we use the Foster et al. (1984) indexes FGT0, FGT1 and FGT2. FGT0 reflect changes in the incidence of poverty, FGT1 reflects the depth of poverty, measured by the poverty gap, and FGT2 which reflects the severity of poverty.

Table 3.8: Effects on poverty

Poverty indicator	Baseline scenario (in %)	Simulation 1 (in %)		Simulation 2 (in %)	
		Short Run	Long run	Short Run	Long run
Rural areas					
Men					
FGT0	51.6	57.0	52.8	56.2	52.6
FGT1	22.9	26.8	23.5	26.0	23.4
FGT2	14.3	17.1	14.8	16.5	14.7
Women					
FGT0	55.3	60.2	56.1	59.4	56.0
FGT1	24.6	28.3	25.2	27.5	25.1
FGT2	15.0	17.7	15.4	17.2	15.4
Urban Areas					
Men					
FGT0	30.8	36.4	31.8	35.4	31.7
FGT1	10.6	12.8	11.0	12.4	10.9
FGT2	4.7	5.8	4.9	5.6	4.8
Women					
FGT0	31.9	37.6	32.9	36.3	32.7
FGT1	10.9	13.0	11.2	12.6	11.2
FGT2	4.9	5.9	5.1	5.7	5.0

Source: Calculations based on the microsimulation model

*Changes in percentage points with respect to the baseline scenario

In the two simulations, poverty increases. However, the rises are slightly lower with reconstruction investment (S2). Moreover, the impact on gender gap increases is also smaller than the no-investment simulation (S1). This suggests that the poverty gap between male and female poverty is successfully narrowing, especially in the long run (see table 3.8). Nevertheless, despite this reduction, female poverty rates remain the highest, especially in rural areas where the poverty headcount exceeds 60%. The results on poverty analysis also reveal an increase in the depth and severity of poverty for both men and women in rural and urban areas.

3.5. Concluding remarks and policy implications

Through an ex-post analysis, this study provides insight into the impacts that climate disasters can have on the Bolivian economy and on women, and also allows for an analysis of the effectiveness of the reconstruction investment policies adopted after the disasters occurred.

On the one hand, the results show that climate disasters have negative impacts on economic activities, aggravate poverty, and increase pre-existing gender inequalities in Bolivia. Moreover, the most negative effects would be suffered by households, especially female-headed households in rural areas, which experience the largest drops in real consumption. On the other hand, investments in infrastructure reconstruction, mainly in the construction and transport sectors, have different effects on the Bolivian economy, which cushion the negative effects of climate disasters but are certainly not sufficient.

At the macroeconomic level, the increase in public investment leads to a recovery of GDP in the long term. In terms of employment, this policy led to the creation of new jobs, mainly in the construction and agricultural sectors in the highlands region. However, the gender analysis of employment and wages favours men more than women. This suggests that labour market gaps remain after the investments are financed by the public deficit. It is important to note that this study has not taken into account the government's fiscal stimulus and social transfer schemes that were introduced after the climate disasters in Bolivia. This is an important issue that should be examined in more detail in future studies. The results of this modelling exercise will therefore be surrounded by some uncertainty. However, they may contribute to guiding the adoption of some appropriate measures in specific areas in the context of climate disasters in Bolivia. In particular, our results allow us to focus our findings on three policy implications.

First, policy options that promote reconstruction help to recover jobs and cushion the negative effects of disasters but are not sufficient for the reduction of gender gaps, especially in the labour market. In this sense, sector-specific investment policies that promote employment generation for women should be considered. In particular, the participation of Bolivian women in non-agricultural economic sectors should be promoted, as their concentration in traditional agricultural sectors highly exposed to climatic disasters make them more vulnerable. Second, support packages should prioritise rural areas, especially rural women, as they are more likely to lose jobs and fall into poverty. These policies could be effective in increasing purchasing power, and curbing the increase in monetary poverty in the short term. Third, measures to diversify production and seek economic growth are necessary to avoid economic dependence on sectors such as minerals, hydrocarbons or soybean production. Policy options could include diversification of agricultural and non-agricultural exports.

Our results contrast with the current reality in Bolivia, which despite advances in economic growth and poverty reduction, still retains high levels of gender inequality in multiple dimensions. Consequently, the possibilities of implementing permanent change for poor women and men, particularly in rural areas, will be seriously affected. Nevertheless, although our results are consistent with what we have observed in reality, and help us to discuss the policy implications presented above, they also have limitations. These imitations are fundamentally framed in three aspects that could invite future research to deepen our analysis.

First, we present an ex-post analysis of climate disasters and the actions taken when they occur. However, we believe that we should also compare the results with those of an ex-post policy that anticipates the occurrence of these events. Secondly, the climate disaster scenario presented refers only to the analysis of destructive events in 2013-2014. Future studies could try to distinguish between the different causes of these events: For example, the analysis of disasters of natural origins such as El Niño and La Niña, vs the analysis of man-made disasters. Thirdly, we have to consider that we model immediate government response to disasters combined with an adaptation policy with reconstruction financed by the public deficit. This is in line with what has been observed in the Bolivian reality. However, future extensions of this study should compare the results using other sources of financing, such as external financing, specific taxes, financing with cuts in public spending, or even a combination of different sources of financing to find the most efficient financing scheme.

Conclusion générale

Cette thèse a été motivée par la volonté d'enrichir les réflexions sur les impacts socio-économiques du changement climatique en Bolivie. Le choix porté sur ce pays s'explique par le fait que la Bolivie traverse actuellement une période d'opportunités sans précédent pour un changement social positif. Cela s'est traduit par une croissance économique soutenue au cours des dernières années et une réduction substantielle de la pauvreté. Toutefois, en raison des vulnérabilités existantes résultant de l'impact du changement climatique et de la persistance des inégalités entre les sexes, notamment sur le marché du travail, la possibilité de mettre en œuvre des changements permanents pour les femmes est menacé.

Malgré les progrès réalisés dans ce pays, les inégalités de genre sur le marché du travail persistent et placent les femmes dans une situation d'extrême vulnérabilité. Cette vulnérabilité est renforcée, surtout si l'on considère la sphère non commerciale de l'économie, où les activités non génératrices de revenus concernent principalement les femmes Boliviennes.

Pour apprécier ce contexte particulier, l'introduction générale de ce travail présente quelques éléments qui justifient la nécessité d'intégrer le genre dans l'analyse du changement climatique dans ce pays. En effet, la division du travail entre les sexes, les différences de préférences entre les hommes et les femmes, en termes de consommation, d'épargne et d'investissement, ou encore les contraintes imposées par rapport à leur rôle reproductif dans le ménage sont des facteurs qui influencent les performances macroéconomiques et surtout créent une situation de haute vulnérabilité pour les femmes boliviennes dans un contexte marqué par le changement climatique.

La problématique générale de cette étude porte donc sur l'analyse des impacts du changement climatique sur les activités économiques agricoles et non-agricoles ainsi que sur des dimensions telles que la pauvreté, la sécurité alimentaire et le bien-être, dans une perspective de genre. Pour aborder cette problématique, nous utilisons le modèle d'équilibre général calculable comme principal cadre de modélisation, et nous adoptons une approche descendante (Top-down), qui combine le modèle d'équilibre général avec un module de microsimulation. Ainsi, les modèles présentés dans les trois articles de cette thèse cherchent à représenter le plus fidèlement possible l'économie bolivienne et à inclure dans la modélisation certains aspects peu visibles et donc peu pris en compte dans les études de ce type, notamment les aspects liés à la réalisation du travail domestique non rémunéré.

Dans les deux premiers chapitres de cette thèse, notre principale contribution concerne la modélisation de la production de biens dans le ménage, en distinguant le travail des hommes et des femmes en fonction de leur niveau de qualification (qualifiés et non qualifiés). Les résultats les plus importants de ces deux premiers chapitres sont en accord avec la littérature sur le fait que les différents effets du changement climatique ne sont pas neutres du point de vue du genre et que les changements dans le secteur marchand se transmettent à la sphère non marchande de l'économie, affectant principalement les femmes dans les zones et régions ayant un secteur rural important.

Dans le premier chapitre, nous présentons un modèle d'équilibre général statique, qui vise à analyser si les effets du changement climatique sur le marché du travail et sur les tâches ménagères dans une perspective de genre. Nous investiguons également si le changement climatique aggrave les différences existantes entre les hommes et les femmes, d'une part, et entre les zones rurales et urbaines, d'autre part. Les chocs simulés dans ce chapitre sont également liés aux impacts à long terme sur les rendements de la production agricole, à l'augmentation des prix internationaux due au changement climatique et aux dommages causés au capital agricole. Les résultats révèlent que les scénarios de changement climatique analysés affectent différemment les hommes et les femmes, les disparités préexistantes entre les sexes s'aggravant dans tous les scénarios. Dans tous les scénarios, l'emploi diminue sensiblement et la charge de travail domestique augmente dans des proportions encore plus importantes, surtout pour les femmes non qualifiées. En outre, ils révèlent également des impacts négatifs sur la pauvreté avec une prééminence chez les femmes des zones rurales.

Dans le deuxième chapitre, nous utilisons une matrice de comptabilité sociale avec un niveau de désagrégation très détaillé dans le secteur agricole, ce qui nous permet de concevoir un modèle plus complet qui prend en compte les chocs régionaux, en particulier dans le secteur agricole. Dans ce chapitre, nous nous intéressons d'une part à l'analyse des catastrophes climatiques sur la sécurité alimentaire et la pauvreté alimentaire des femmes et d'autre part, aux répercussions que cela peut avoir l'inégalité des sexes en Bolivie. Le modèle d'équilibre général de ce chapitre présente également un cadre statique, mais il diffère du premier grâce à l'inclusion des impacts sur les secteurs non agricoles en plus des secteurs agricoles d'une part et avec l'analyse de la sécurité alimentaire dans une perspective de genre et régionale d'autre part. En effet, étant donné la diversité du paysage bolivien, nous analysons un scénario dans lequel des dommages régionaux spécifiques se produisent dans différents secteurs économiques en raison d'événements climatiques défavorables. À cette fin, le modèle d'équilibre général de ce chapitre

présente une analyse ex post des dommages induits par les catastrophes climatiques survenues entre 2013 et 2014 sur la sécurité alimentaire et la pauvreté alimentaire des femmes. Les résultats de ce chapitre révèlent qu'à travers la Bolivie, la vulnérabilité des femmes et des hommes à l'impact des catastrophes climatiques n'est pas égale en raison des différences régionales et de genre. La simulation révèle des impacts négatifs sur l'économie bolivienne, notamment dans le domaine de l'agriculture. Les disponibilités alimentaires sont réduites, les prix des aliments augmentent et la capacité économique des ménages à accéder à la nourriture diminue. En conséquence, l'insécurité alimentaire et la pauvreté alimentaire s'aggravent, les ménages dirigés par des femmes étant les plus touchés. Les résultats révèlent également des effets négatifs sur l'emploi et une augmentation de la charge des ménages, en particulier chez les femmes des hautes terres. Ces résultats révèlent la nécessité d'intégrer la dimension de genre dans les politiques d'analyse et de prévention des catastrophes climatiques.

Dans le troisième et dernier chapitre, nous avons étendu le modèle statique du deuxième chapitre pour étudier l'impact des désastres climatiques, mais aussi des réponses gouvernementales pour contrecarrer les effets destructeurs des catastrophes. Le modèle que nous avons appliqué est un modèle dynamique permettant de saisir les différents effets à long terme. Les questions abordées dans ce chapitre englobent les liens entre les catastrophes climatiques et les inégalités de femmes hommes en matière de pauvreté et sur le marché du travail. A cela s'ajoute la recherche des politiques à adopter pour parvenir à une réduction inclusive des risques induits par les catastrophes climatiques sur les différents phénomènes ci-dessus. En prenant comme étude de cas les dommages enregistrés en Bolivie entre 2013 et 2014 à la suite des catastrophes climatiques, ce chapitre utilise un modèle dynamique d'équilibre général calculable pour analyser les impacts socioéconomiques des catastrophes climatiques et de la reconstruction sur le marché du travail et la pauvreté dans une perspective de genre. Les résultats révèlent que les dommages causés par les catastrophes ont des effets négatifs sur l'économie, tandis que les investissements dans la reconstruction ont des effets positifs. Cependant, il n'y a pas d'améliorations claires dans la réduction des écarts entre les sexes qui subsistent même après la reconstruction. En fait, nous constatons que la pauvreté monétaire et la pauvreté alimentaire sont réduites par les politiques d'investissement, mais elles restent plus élevées chez les femmes, principalement dans les zones rurales. Sur le marché du travail, les catastrophes entraînent la destruction d'emplois pour tous les travailleurs, tandis que l'investissement dans la reconstruction entraîne la création d'emplois, favorisant légèrement l'emploi des travailleurs masculins non qualifiés et semi-qualifiés.

Bien que nous ayons tenté d'expliquer et de représenter au mieux la réalité de l'économie bolivienne par l'utilisation de modèles d'équilibre général calculable, il convient de noter qu'il existe plusieurs limites en termes de choix et d'hypothèses de modélisation, de disponibilité des données et de cadre de modélisation en général.

Pour les deux premiers chapitres de cette thèse, qui incluent la modélisation de la production des ménages en plus de la production commerciale, la disponibilité de données existantes pour la Bolivie joue un rôle important dans le choix de la modélisation. Une perspective intéressante serait d'inclure les comptes liés à la production des ménages comme de nouveaux secteurs dans la matrice de comptabilité sociale. En effet, plusieurs études choisissent d'utiliser ce cadre de modélisation en désagrégant les matrices de comptabilité sociale dans une perspective de genre (Fontana, 2004; Fontana & Wood, 2000; Siddiqui, 2009). Toutefois, cela nécessite des données qui permettent l'inclusion de ces comptes et, idéalement, l'accès à une enquête sur l'utilisation du temps avec un niveau de désagrégation détaillé. Pour contourner cet inconvénient, nous utilisons un cadre de modélisation alternatif observé dans des études telles que Fofana et al. (2003) ou Terra et al. (2009), qui propose une offre de travail endogène dans laquelle les ménages divisent leur allocation de temps entre les activités du ménage, les loisirs et les activités de marché. Cette méthode est utile dans des pays comme la Bolivie où l'information n'est pas disponible, mais il faut garder à l'esprit qu'elle implique également de faire face à un degré élevé de sensibilité par rapport aux valeurs d'élasticité qui sont fixées notamment sur le marché du travail. De même, toujours en raison de la disponibilité des données existantes pour la Bolivie, nous ne considérons qu'une désagrégation entre les activités marchandes et les activités domestiques des ménages. Toutefois, en réalité, en plus des activités ménagères, il serait utile d'inclure les activités de loisirs des hommes et des femmes. Cela nous permettrait de voir si, par exemple, une éventuelle création d'emplois après un investissement dans l'adaptation au climat se fait par la réduction des loisirs ou du travail domestique. D'autre part, l'utilisation de modèles statiques dans ces deux chapitres nous empêche de considérer les éventuels effets de redistribution qui pourraient se produire dans le temps. Enfin, aucune politique d'adaptation n'est envisagée, même si le gouvernement a tendance à réagir et à accélérer les programmes d'investissement, notamment en cas de catastrophes climatiques, analysées dans le chapitre 2 de cette thèse.

Ces limites, qui concernent les deux premiers chapitres de cette thèse offrent ensuite des prolongements possibles. En particulier, l'inclusion du temps libre dans le modèle ainsi que la segmentation des activités du ménage en tâches spécifiques telles que la garde des enfants, la

préparation des repas, le nettoyage, la collecte de l'eau, la collecte du bois de chauffage, etc. pourraient permettre d'avoir une représentation plus réaliste de la réalité bolivienne et d'affiner les effets liés au climat en considérant toutes ces interactions. Toutefois, cela nécessite à nouveau des données permettant l'intégration de tous ces éléments. De même, la comparaison des résultats du cadre de modélisation utilisé dans cette thèse avec ceux qui choisissent d'inclure ces activités rémunérées et non rémunérées comme de nouveaux comptes dans la matrice de comptabilité sociale pourrait être pertinente et mettre en lumière les divergences entre les différents cadres de modélisation sur le sujet.

Une autre extension possible du modèle serait de passer d'un modèle statique à un modèle dynamique qui pourrait permettre l'évaluation des effets intertemporels liés au changement climatique, aux activités rémunérées et non rémunérées (bien que cela puisse être compliqué en raison de l'ampleur des données requises).

Par ailleurs, l'utilisation d'élasticités différentes dans les ménages et d'élasticités sur le marché du travail selon le sexe repose sur des estimations d'études antérieures, étant donné l'absence d'estimations spécifiques pour la Bolivie. Dans cette étude, nous avons eu recours à des tests de sensibilité qui nous ont permis de vérifier la robustesse de nos résultats. Toutefois, les études futures devraient s'efforcer d'estimer des élasticités spécifiques à la Bolivie qui représentent mieux la réalité du marché du travail bolivien et la réalité de la production des ménages.

Quant au troisième chapitre, bien qu'il s'agisse d'un modèle dynamique, il présente également des limites qui donnent lieu à de futures extensions du modèle. Tout d'abord, la conception de notre scénario de catastrophe climatique se réfère uniquement à l'analyse des événements destructeurs vécus par la Bolivie en 2013-2014. Les études futures pourraient s'étendre et faire une analyse plus générale de l'impact des catastrophes climatiques dans ce pays, en tenant compte des origines naturelles comme El Niño et La Niña et des catastrophes d'origine humaine comme les incendies. Deuxièmement, le cadre ex-post adopté dans cette étude est important pour analyser des phénomènes spécifiques à une période donnée et pour comprendre les effets de premier et de second ordre sur l'économie dans son ensemble. Il convient toutefois de noter que l'intensité avec laquelle les phénomènes naturels se produisent n'est pas la même sur une longue période, car elle a considérablement variée au fil des ans. En ce sens, l'intégration d'aspects tels que les probabilités d'occurrence de phénomènes spécifiques, compte tenu de l'histoire des catastrophes survenues dans ce pays par le passé, serait pertinente, notamment dans le cadre d'études de prévention ex ante à long terme.

Troisièmement, il faut également considérer que la réponse du gouvernement aux catastrophes climatiques simulée dans ce chapitre est basée sur l'adoption d'une politique unique d'investissement dans les infrastructures l'année même de l'événement, et sur l'analyse des politiques de reconstruction dans le cadre du plan « Patujú ». Ceci est insuffisant, car dans la pratique, une combinaison de politiques économiques avec des transferts immédiats vers les personnes les plus touchées et des politiques d'adaptation à plus long terme pourrait être une réponse plus appropriée pour traiter cette question. De même, nous utilisons une seule source de financement, le déficit public. Les extensions ultérieures de ce travail devraient comparer les résultats en utilisant d'autres sources de financement telles que le financement externe, les taxes spécifiques, le financement avec des réductions des dépenses publiques, ou même une combinaison de différentes sources de financement afin de trouver le plan de financement le plus efficace.

Par conséquent, il existe de nombreuses questions à prendre en compte afin de saisir les diverses implications de l'intégration de la dimension de genre dans l'analyse du changement climatique, qui peuvent être approfondies dans les recherches futures. Cependant, cette thèse apporte un éclairage sur cette question et nous permet de formuler des recommandations politiques spécifiques à la lumière de nos résultats. Le nombre croissant d'études visant à évaluer les effets du changement climatique, ainsi que les initiatives d'adaptation aux niveaux national, régional et même local, suggèrent que la Bolivie a franchi les premières étapes très importantes du processus de compréhension et de réponse aux effets du changement climatique. Toutefois, le pays doit encore élaborer et mettre en œuvre des politiques qui adoptent une approche plus globale.

Sur la base des principaux résultats obtenus dans les trois chapitres, nous pouvons conclure qu'il est nécessaire de mettre en œuvre des politiques et des pratiques efficaces dans le processus d'adaptation aux risques climatiques extrêmes et au changement climatique, qui ne se concentrent pas uniquement sur la reconstruction ou le secteur agricole, mais cherchent également à créer des emplois qui soutiennent les femmes et comblent les écarts entre les sexes. Les deux premiers articles de cette thèse mettent en évidence le fait que le changement climatique et les catastrophes climatiques aggravent les écarts entre les sexes sur le marché du travail, et que la destruction des emplois et des infrastructures se traduit par une augmentation des charges domestiques pour les femmes, principalement dans les zones rurales, ce qui creuse davantage les écarts préexistants entre les sexes. Ces interconnexions doivent être prises en

compte lors de l'élaboration d'un cadre politique public et institutionnel sur l'adaptation au changement climatique et l'atténuation de ses effets.

De même, une stratégie d'adaptation devrait être mise en œuvre en tant qu'élément transversal de la stratégie d'éradication de la pauvreté. Les politiques de reconstruction que nous avons simulées montrent que les investissements dans une situation de catastrophe ex-post parviennent à freiner l'augmentation de la pauvreté. Ainsi, les politiques d'adaptation devraient tirer parti de ces synergies pour réduire l'augmentation de la pauvreté en conjonction avec des politiques d'adaptation appropriées. En outre, la mise en œuvre de cette stratégie doit être axée sur la région et le genre, car nous avons identifié tout au long de notre travail que les impacts ne sont pas neutres en termes de genre et de localisation, les femmes des zones rurales, les femmes de la région des hauts plateaux et les femmes de la région des vallées étant les plus vulnérables.

Enfin, la réduction des risques de catastrophe ne doit pas être envisagée uniquement au lendemain des catastrophes ou à court terme. Elle devrait plutôt être incluse dans des plans à long terme qui placent les femmes au centre de ceux-ci. En effet, les femmes sont particulièrement vulnérables aux pires impacts climatiques, mais jouent en même temps un rôle central dans la protection de leur famille. Par conséquent, afin de parvenir à une adaptation efficace au climat dans les zones rurales et pauvres, le gouvernement ne doit pas perdre de vue la nécessité de maintenir les femmes au centre des politiques nationales d'adaptation et de réduction de la vulnérabilité aux catastrophes.

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Annexes

Appendix A.1 : Annexe du Chapitre 1

S.1. Institutional desegregation and model sets

All activities or Commodities (20)

{cer, veg, root, fruit, otniag, oilsee, sucana, coca, live, forfish, hydromin, foodp, tobac, text, machi, utility, tradefin, reshot, social, adm}

Agricultural activities (Traditional and Modern)

- **Traditional agricultural industries (5):**
{cer, veg, root, fruit, otniag}
- **Modern agricultural industries (3):**
{oilsee, sucana, coca}

cer: Cereals
veg: Vegetables
root: Root crops
fruit: Fruits
otniag: Other agricultural activities
oilsee: Soya
sucana: Sugar cane
coca: Coca crops
live: Livestock
forfish: Forestry and fishing
hydromin: Hydrocarbon and mining industry
foodp: Food industry
tobac: Tobacco industry
text: Textile industry
machi: Machinery and other industries
utility: Water, gas and electricity industry
tradefin: Trade and financial services industry
reshot: Restaurants and hotels
social: Municipal and social services
adm: Public administration

Agents (7)

Non-governmental agent (1):

{gvt}

Rest of the world (1):

{row}

Firms (1):

{f}

Households (4):

{hhrh, hhrf, hhuh, hhuf}

hhrh: Rural male headed household

hhrf: Rural female headed household

hhuh: Urban male headed household

hhuf: Urban female headed household

Production factors (8)

Labour categories (4):

$l \in L = \{USKM, USKF, SKLM, SKLF\}$

USKH: Unskilled workers male

SKLH: Skilled workers male

USKF: Unskilled workers female

SKLF: Skilled workers female

Capital categories (4):

$k \in K = \{CAP, LND1, LND2, LND3\}$

CAP: Capital,

LND1: Land highlands

LND2: Land lowlands

LND3: Land valleys

S.2. List of variables and parameters

Volume variables

$C_{i,h}$:	Consumption of commodity i by type h households
$C_{i,h}^{MIN}$:	Minimum consumption of commodity i by type h households
CG_i :	Public consumption of commodity i
CI_j :	Total intermediate consumption of industry j
CTH_h^{REAL} :	Real consumption expenditures of household h
DD_i :	Domestic demand for commodity i produced locally
$DI_{i,j}$:	Intermediate consumption of commodity i by industry j
DIT_i :	Total intermediate demand for commodity i
$DS_{j,i}$:	Supply of commodity i by sector j to the domestic market
$EX_{j,i}$:	Quantity of product i exported by sector j
EXD_i :	World demand for exports of product i
G^{REAL} :	Real government expenditures
$GDP^{BP,REAL}$:	Real GDP at basic prices
$GDP^{MP,REAL}$:	Real GDP at market prices
$GFCF^{REAL}$:	Real gross fixed capital formation
IM_i :	Quantity of product i imported
INV_i :	Final demand of commodity i for investment purposes (GFCF)
KDC_j :	Industry j demand for composite capital
LHQ_j :	Industry j demand for male skilled labour
LFQ_j :	Industry j demand for female skilled labour
$LHNQ_j$:	Industry j demand for male unskilled labour
$LFNQ_j$:	Industry j demand for female unskilled labour
LQ_j :	Industry j demand for skilled labour
LNQ_j :	Industry j demand for unskilled labour
LDC_j :	Industry j demand for composite labour

$MRGN_i$:	Demand for commodity i as a trade or transport margin
Q_i :	Quantity demanded of composite commodity i
VA_j :	Value added of industry j
$XS_{j,i}$:	Industry j production of commodity i
XST_j :	Total aggregate output of industry j

Home production and Labour supply variables

P_h^{HOM} :	Purchase price of home-produced commodities by type h households
CZ_h :	Consumption of home-produced commodities by type h households
Z_h :	Home production for each type of household
$LSFNQ_h$:	Household H female unskilled market labour supply
$LSHNQ_h$:	Household H male unskilled market labour supply
$LSFQ_h$:	Household H female skilled market labour supply
$LSHQ_h$:	Household H male skilled market labour supply
$LZHNQ_h$:	Household H male unskilled time used to produce home commodities
$LZFNQ_h$:	Household H female unskilled time used to produce home commodities
$LZHQ_h$:	Household H male skilled time used to produce home commodities
$LZFQ_h$:	Household H female skilled time used to produce home commodities
LZH_h :	Household H male time used to produce home commodities
LZF_h :	Household H female time used to produce home commodities

Price variables

$P_{j,i}$:	Basic price of industry j's production of commodity i
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TIKT: Total government revenue from taxes on capital
TIM_i: Government revenue from import duties on product i
TIMT: Total government revenue from import duties
TIP_j: Government revenue from taxes on industry j production (excluding taxes directly related to the use of capital and labour)
TIPT: Total government revenue from production taxes (excluding taxes directly related to the use of capital and labour)
TIW_{l,j}: Government revenue from payroll taxes on type l labour in industry j
TIWT: Total government revenue from payroll taxes
TIX_i: Government revenue from export taxes on product i
TIXT: Total government revenue from export taxes
TPRCTS: Total government revenue from taxes on products and imports
TPRODN: Total government revenue from other taxes on production
TR_{ag,agj}: Transfers from agent agj to agent ag
YDF_f: Disposable income of type f businesses
YDH_h: Disposable income of type h households
YF_f: Total income of type f businesses
YFK_f: Capital income of type f businesses
YFTR_f: Transfer income of type f businesses
YG: Total government income
YGK: Government capital income
YGTR: Government transfer income
YH_h: Total income of type h households
YHK_h: Capital income of type h households
YHL_h: Labour income of type h households
YHTR_h: Transfer income of type h households
YROW: Rest-of-the-world income

TPFT: Productivity parameter (traditional agriculture)
TPFM: Productivity parameter (modern agriculture)

Exogenous variables and closures

G: Current government expenditures on goods and services
KD_{k,j}: Demand for type k capital by industry j
KS_k: Supply of type k capital
VSTK_i: Inventory change of commodity i
CZ_{i,h}^{MIN}: Minimum consumption of home-produced commodities (LES consumption function)
CAB: Current account balance
PWM_i: World price of imported product i (expressed in foreign currency)
PWX_i: World price of exported product i (expressed in foreign currency)
e: Exchange rate (price of foreign currency in local currency)

Rates and intercepts

sh0_h: Intercept (type h household savings)
sh1_h: Slope (type h household savings)
tr0_h: Intercept (transfers by type h households to government)
tr1_h: Marginal rate of transfers by type h households to government
ttdf0: Intercept (income taxes of type f businesses)
ttdf1: Marginal income tax rate of type f businesses
ttdh0_h: Intercept (income taxes of type h households)
ttdh1_h: Marginal income tax rate of type h households
ttic_i: Tax rate on commodity i
ttik_{k,j}: Tax rate on type k capital used in industry j
ttim_i: Rate of taxes and duties on imports of commodity i
ttip_j: Tax rate on the production of industry j

$tti_{l,j}$: Tax rate on type l worker compensation in industry j
 $ttix_i$: Export tax rate on exported commodity i

Parameters linked to labour market and home-production

$MAXHOUR_h^{malnq}$: Maximum time available for unskilled male in household h

$MAXHOUR_h^{malq}$: Maximum time available for skilled male in household h

$MAXHOUR_h^{femna}$: Maximum time available for unskilled female in household h

$MAXHOUR_h^{fema}$: Maximum time available for skilled female in household h

z_h^{femna} : Household H's share of unskilled female home consumption

z_h^{fema} : Household H's share of skilled female home consumption

z_h^{malna} : Household H's share of unskilled male home consumption

z_h^{malq} : Household H's share of skilled male home consumption

z_h^{hom} : Household H's share of home consumption

$LELAS_h^{femna}$: Household H's elasticity of unskilled female labour supply with respect to income

$LELAS_h^{fema}$: Household H's elasticity of skilled female labour supply with respect to income

$LELAS_h^{malna}$: Household H's elasticity of unskilled male labour supply with respect to income

$LELAS_h^{malq}$: Household H's elasticity of skilled male labour supply with respect to income

Ψ_h^{hom} : Consumption elasticity of household goods

$\gamma_{i,h}^{LES}$: Marginal share of commodity i in household h consumption budget

Ψ_h^{hom} : Consumption elasticity of household goods

B_h^{zlab} : Scale parameter (CES – composite home production)

B_h^{zlabh} : Scale parameter (CES – male home production)

B_h^{zlabf} : Scale parameter (CES – female home production)

β_h^{zlab} : Share parameter (CES – composite home production)

β_h^{zlabh} : Share parameter (CES – male home production)

β_h^{zlabf} : Share parameter (CES – female home production)

ρ_h^{zlab} : Elasticity parameter (CES – composite home production)

ρ_h^{zlabh} : Elasticity parameter (CES – male home production)

ρ_h^{zlabf} : Elasticity parameter (CES – female home production)

σ_h^{zlab} : Elasticity (CES – composite home production)

σ_h^{zlabh} : Elasticity (CES – male home production)

σ_h^{zlabf} : Elasticity (CES – female home production)

B_j^{LDC} : Scale parameter (CES – composite labour)

B_j^{LQ} : Scale parameter (CES – Skilled labour)

B_j^{LNQ} : Scale parameter (CES – unskilled labour)

β_j^{LDC} : Share parameter (CES – composite labour)

β_j^{LQ} : Share parameter (CES – Skilled labour)

β_j^{LNQ} : Share parameter (CES – unskilled labour)

ρ_j^{LDC} : Elasticity parameter (CES – composite labour)

ρ_j^{LQ} : Elasticity parameter (CES – Skilled labour)

ρ_j^{LNQ} : Elasticity parameter (CES – Unskilled labour)

σ_j^{LDC} : Elasticity (CES – Skilled labour)

σ_j^{LQ} : Elasticity (CES – Skilled labour)

σ_j^{LNQ} : Elasticity (CES – unskilled labour)

Other parameters

$aij_{i,j}$:	Input-output coefficient
B_j^{KD} :	Scale parameter (CES - composite capital)
B_j^{VA} :	Scale parameter (CES - value added)
$B_{j,i}^X$:	Scale parameter (CET - exports and local sales)
B_j^{XT} :	Scale parameter (CET - total output)
$\beta_{k,j}^{KD}$:	Share parameter (CES - composite capital)
β_i^M :	Scale parameter (CES - composite commodity)
β_j^{VA} :	Share parameter (CES - value added)
$\beta_{j,i}^X$:	Share parameter (CET - exports and local sales)
$\beta_{j,i}^{XT}$:	Share parameter (CET - total output)
η :	Price elasticity of indexed transfers and parameters
$frish_h$:	Frisch parameter (LES function)
γ_i^{GVT} :	Share of commodity i in total current public expenditures on goods and services
γ_i^{INV} :	Share of commodity i in total investment expenditures
io_j :	Coefficient (Leontief - intermediate consumption)
K^{MOB} :	Flag parameter (1 if capital is mobile)
$\lambda_{ag,k}^{RK}$:	Share of type k capital income received by agent ag
$\lambda_{ag,agj}^{TR}$:	Share parameter (transfer functions)
λ_h^{wmnq} :	Share of male unskilled labour income received by type h households
λ_h^{wfnq} :	Share of female unskilled labour income received by type h households
λ_h^{wmq} :	Share of male skilled labour income received by type h households
λ_h^{wfq} :	Share of female skilled labour income received by type h households

ρ_j^{KD} :	Elasticity parameter (CES - composite capital)
ρ_i^M :	Elasticity parameter (CES - composite commodity)
ρ_j^{VA} :	Elasticity parameter (CES - value added)
$\rho_{j,i}^X$:	Elasticity parameter (CET - exports and local sales)
ρ_j^{XT} :	Elasticity parameter (CET - total output)
σ_j^{KD} :	Elasticity (CES - composite capital)
σ_i^M :	Elasticity (CES - composite commodity)
σ_j^{VA} :	Elasticity (CES - value added)
$\sigma_{j,i}^X$:	Elasticity (CET - exports and local sales)
σ_j^{XT} :	Elasticity (CET - total output)
σ_i^{XD} :	Price elasticity of the world demand for exports of product i
$\sigma_{i,h}^Y$:	Income elasticity of consumption
$tmr g_{i,ij}$:	Rate of margin i applied to commodity ij
$tmr g_{i,ij}^X$:	Rate of margin i applied to exported commodity i
v_j :	Coefficient (Leontief - value added)

S.3. Model equations

Production

1. $VA_j = v_j XST_j$
2. $Cl_j = i_{0j} XST_j$
3. $VA_{agrt} = TPFT \left\{ B_{agrt}^{VA} \left[\beta_{agrt}^{VA} LD_{agrt}^{-\rho_{agrt}^{VA}} + (1 - \beta_{agrt}^{VA}) KD_{agrt}^{-\rho_{agrt}^{VA}} \right]^{-\frac{1}{\rho_{agrt}^{VA}}} \right\}$
4. $VA_{agrm} = TPFM \left\{ B_{agrm}^{VA} \left[\beta_{agrm}^{VA} LD_{agrm}^{-\rho_{agrm}^{VA}} + (1 - \beta_{agrm}^{VA}) KD_{agrm}^{-\rho_{agrm}^{VA}} \right]^{-\frac{1}{\rho_{agrm}^{VA}}} \right\}$
5. $VA_{nagr} = B_{nagr}^{VA} \left[\beta_{nagr}^{VA} LD_{nagr}^{-\rho_{nagr}^{VA}} + (1 - \beta_{nagr}^{VA}) KD_{nagr}^{-\rho_{nagr}^{VA}} \right]^{-\frac{1}{\rho_{nagr}^{VA}}}$
6. $LDC_j = \left\{ \left[\frac{\beta_j^{YA}}{(1-\beta_j^{YA})} \right] \left[\frac{RC_j}{WC_j} \right] \right\}^{\sigma_j^{YA}} KDC_j$
7. $LDC_j = B_j^{LDC} \left[\beta_j^{LDC} LQ_j^{-\rho_j^{LDC}} + (1 - \beta_j^{LDC}) LNQ_j^{-\rho_j^{LDC}} \right]^{-1/\rho_j^{LDC}}$
8. $LQ_j = \left\{ \left[\frac{\beta_j^{LDC}}{(1-\beta_j^{LDC})} \right] \left[\frac{WNQ_j}{WQ_j} \right] \right\}^{\sigma_j^{LDC}} LNQ_j$
9. $LQ_j = B_j^{LQ} \left[\beta_j^{LQ} LHQ_j^{-\rho_j^{LQ}} + (1 - \beta_j^{LQ}) LFNQ_j^{-\rho_j^{LQ}} \right]^{-1/\rho_j^{LQ}}$
10. $LHQ_j = \left\{ \left[\frac{\beta_j^{LQ}}{(1-\beta_j^{LQ})} \right] \left[\frac{WFQ_j}{WHQ_j} \right] \right\}^{\sigma_j^{LQ}} LFNQ_j$
11. $LNQ_j = B_j^{LNQ} \left[\beta_j^{LNQ} LHNQ_j^{-\rho_j^{LNQ}} + (1 - \beta_j^{LNQ}) LFNQ_j^{-\rho_j^{LNQ}} \right]^{-1/\rho_j^{LNQ}}$
12. $LHNQ_j = \left\{ \left[\frac{\beta_j^{LNQ}}{(1-\beta_j^{LNQ})} \right] \left[\frac{WFNQ_j}{WHNQ_j} \right] \right\}^{\sigma_j^{LNQ}} LFNQ_j$
13. $KDC_j = B_j^{KD} \left[\sum_k \beta_j^{KD} KD_{k,j}^{-\sigma_j^{KD}} \right]^{-1/\sigma_j^{KD}}$
14. $KD_{k,j} = \left[\frac{\beta_j^{KD} RC_j}{RT_{k,j}} \right]^{\sigma_j^{KD}} B_j^{KD} (\sigma_j^{KD} - 1) KDC_j$
15. $DI_{i,j} = ai_{i,j} Cl_j$

Income and Savings

Households

16. $YH_h = YHL_h + YHK_h + YHTR_h$
17. $YHL_h = Wfq LSFQ_h + Whq LSHQ_h + Wfnq LSFNQ_h + Whnq LSHNQ_h$
18. $YHK_h = \lambda_h^{RK} (\sum_j R_j KD_j)$
19. $YHTR_h = \sum_{ag} TR_{h,ag}$
20. $YDH_h = YH_h - TDH_h - TR_{gvt,h}$
21. $CTH_h = YDH_h - SH_h - \sum_{agn} TR_{agn,h}$
22. $SH_h = PIXCON^S SH_0 + SH_{1,h} YDH_h$

Firms

23. $YF = YFK + YFTR$
24. $YFK = \sum_k \lambda_k^{RK} (\sum_j R_{k,j} KD_{k,j})$
25. $YFTR = \sum_{ag} TR_{f,ag}$
26. $YDF = YF - TDF$
27. $SF = YDF - \sum_{ag} TR_{ag,f}$

Government

28. $YG = YGK + TDHT + TDF + TPROD + TPRCTS + YGTR$
29. $YGK = \lambda_{gvt}^{RK} (\sum_j R_j KD_j)$
30. $TDHT = \sum_h TDH_h$
31. $TDF = \sum_h TDF_f$
32. $TPRODN = TIWT + TIKT + TIPT$
33. $TIWT = \sum_{i,j} TIW_{i,j}$

34. $TIKT = \sum_{k,j} TIK_{k,j}$
35. $TIPT = \sum_j TIP_j$
36. $TPRCTS = TICT + TIMT + TIXT$
37. $TICT = \sum_i TIC_i$
38. $TIMT = \sum_i TIM_i$
39. $TIXT = \sum_i TIX_i$
40. $YGTR = \sum_{agn} TR_{gvt,agn}$
41. $TDH_h = PIXCON^N ttdh0_h + ttdh1_h YH_h$
42. $TDF_f = PIXCON^N ttdf0_h + ttdh1_f YFK_f$
43. $TIW_{i,j} = ttw_{i,j} \{ Whnq LHNQ_j + Wfnq LFNQ_j + Whq LHQ_j + Wfq LQ_j \}$
44. $TIK_{k,j} = ttik_{k,j} R_{k,j} KD_{k,j}$
45. $TIP_j = ttip_j P_j XST_j$
46. $TIC_i = ttic_i \left\{ (PL_i + \sum_{ij} PC_{ij} tmr_{g_{ij},i}) DD_i \left((1 + ttim_i) PWM_{i,e} + \sum_{ij} PC_{ij} tmr_{g_{ij},i} \right) IM_i \right\}$
47. $TIM_i = ttim_i PWM_{i,e} IM_i$
48. $TIX_i = ttx_i (PE_i + \sum_{ij} PC_{ij} tmr_{g_{ij},i}^x) EXD_i$
49. $SG = YG - \sum_{agn} TR_{agn,gvt} - G$

Rest of the world

50. $YROW = e \sum_i PWM_{i,IM_i} + \lambda_{row}^{RK} (\sum_j R_j KD_j) + \sum_{agd} TR_{row,agd}$
51. $SROW = YROW - \sum_i PE_i^{FOB} EX_i - \sum_{agd} TR_{agd,row}$
52. $SROW = -CAB$

Transfers

53. $TR_{agn,h} = \lambda_{agn,h}^{TR} YDH_h$
54. $TR_{gvt,h} = PIXCON^N tr0_h tr1_h YH_h$
55. $TR_{ag,f} = \lambda_{ag,f}^{TR} YDF_f$
56. $TR_{agn,gvt} = PIXCON^N TR_{agn,gvt}^0$
57. $TR_{agd,row} = PIXCON^N TR_{agd,row}^0$

Demand

58. $PC_i C_{i,h} = PC_i C_{i,h}^{MIN} + \left(\frac{v_{i,h}^{LES}}{(1 - z_h^{emna} - z_h^{maina} - z_h^{ema} - z_h^{ma} - z_h^{hom})} \right) (CTH_h - \sum_{ij} PC_{ij} C_{ij,h}^{MIN})$
59. $CZ_h P_h^{hom} = CZ_h^{MIN} P_h^{hom} + \left(\frac{z_h^{hom}}{(1 - z_h^{emna} - z_h^{maina} - z_h^{ema} - z_h^{ma} - z_h^{hom})} \right) (CTH_h - \sum_{ij} PC_{ij} C_{ij,h}^{MIN})$
60. $GFCF = IT - \sum_i PC_i VSTK_i$
61. $PC_i INV_i = \gamma_i^{INV} GFCF$
62. $PC_i CG_i = \gamma_i^{GVT} G$
63. $DIT_i = \sum_j DI_{i,j}$
64. $MRGN_i = \sum_{ij} tmr_{g_{ij},i} DD_{ij} + \sum_{ij} tmr_{g_{ij},i} IM_{ij} + \sum_{ij} tmr_{g_{ij},i}^x EXD_{ij}$

International trade

65. $XST_j = B_j^{XT} \left[\sum_i \beta_{j,i}^{XT} X S_{j,i}^{\rho_j^{XT}} \right]^{\frac{1}{\rho_j^{XT}}}$
66. $X S_{j,i} = \frac{XST_j}{(B_j^{XT})^{1+\sigma_j^{XT}}} \left[\frac{P_{j,i}}{\beta_{j,i}^{XT} PT_j} \right]^{\sigma_j^{XT}}$
67. $X S_{j,i} = B_{j,i}^X \left[\beta_{j,i}^X EX_{j,i}^{\rho_{j,i}^X} + (1 - \beta_{j,i}^X) DS_{j,i}^{\rho_{j,i}^X} \right]^{\frac{1}{\rho_{j,i}^X}}$
68. $EX_{j,i} = \left[\frac{1 - \beta_{j,i}^X PE_i}{\beta_{j,i}^X PL_i} \right]^{\sigma_{j,i}^X} DS_{j,i}$
69. $EXD_i = EXD_i^0 \left(\frac{e PWX_i}{PE_i^{FOB}} \right)^{\sigma_i^{XD}}$
70. $Q_i = B_i^M \left[\beta_i^M IM_i^{-\rho_i^M} + (1 - \beta_i^M) DD_i^{-\rho_i^M} \right]^{\frac{-1}{\rho_i^M}}$
71. $IM_i = \left[\frac{\beta_i^M PD_i}{1 - \beta_i^M PM_i} \right]^{\sigma_i^M} DD_i$

Prices

$$\begin{aligned}
72. & PP_j XST_j = PVA_j VA_j + PC_{ij} CI_j \\
73. & PT_j = (1 + ttip_j) PP_j \\
74. & PC_{ij} CI_j = \sum_i PC_i DI_{i,j} \\
75. & PVA_j VA_j = WC_j LDC_j + RC_j KDC_j \\
76. & WC_j = \frac{LQ_j WQ_j + LNQ_j WNQ_j}{LDC_j} \\
77. & WQ_j = \frac{LHQ_j Whq + LFQ_j Wf q}{LQ_j} \\
78. & WNQ_j = \frac{LHNQ_j Whnq + LFNQ_j Wfnq}{LNQ_j} \\
79. & RTI_j = R_{k,j} (1 + ttik_{k,j}) \\
80. & R_{k,j} = Rk_k \\
81. & P_{j,i} = PT_j \\
82. & P_{j,i} = \frac{PE_i EX_{j,i} + PL_i DS_{j,i}}{XS_{j,i}} \\
83. & PE_i^{FOB} = (PE_i + \sum_{ij} PC_{ij} tmrg_{ij,i}^x) (1 + tti_{x,i}) \\
84. & PD_i = (1 + tti_{c,i}) (PL_i + \sum_{ij} PC_{ij} tmrg_{ij,i}) \\
85. & PM_i = (1 + tti_{c,i}) (1 + tti_{m,i}) e PWM_i + \sum_{ij} PC_{ij} tmrg_{ij,i} \\
86. & PC_i = \frac{PM_i IM_i + PD_i DD_i}{Q_i}
\end{aligned}$$

Price indexes

$$\begin{aligned}
87. & PIXGDP = \frac{\sum_i (PVA_j \frac{TI P_j}{VA_j}) VA_j^0 AO_j \sum_i (PVA_j VA_j + TI P_j)}{\sqrt{\sum_i (PVA_j^0 VA_j^0 + TI P_j^0) \sum_i (PVA_j^0 + \frac{TI P_j^0}{VA_j^0}) VA_j}} \\
88. & PIXCON = \frac{\sum_i PC_i \sum_h C_{i,h}^0}{\sum_i PC_{i,h}^0 \sum_h C_{i,h}^0} \\
89. & PIXINV = \prod_i \left(\frac{PC_i}{PC_i^0} \right)^{Y_i^{INV}} \\
90. & PIXGVT = \prod_i \left(\frac{PC_i}{PC_i^0} \right)^{Y_i^{CVT}}
\end{aligned}$$

Equilibrium and labour supply

$$\begin{aligned}
91. & Q_i = \sum_h C_{i,h} + CG_i + INV_i + VSTK_i + DIT_i + MRGN_i \\
92. & WZHNQ_h = \frac{LSHNQ_h}{Whq LSHQ_h} \\
93. & WZHQ_h = \frac{Whq LSHQ_h}{LSHQ_h} \\
94. & WZFNQ_h = \frac{Wfnq LSFNQ_h}{LSFNQ_h} \\
95. & WZFQ_h = \frac{Wf q LSFQ_h}{LSFQ_h} \\
96. & LSFNQ_h = MAXHOUR_h^{femnq} - LZFNQ_h - \frac{CTH_h - \sum_{ij} [PC_{ij} C_{ij}^{min}]}{[WZFNQ_h (1 - z_h^{femnq} - z_h^{malnq} - z_h^{femaq} - z_h^{malq} - z_h^{hom})]} \\
97. & LSFQ_h = MAXHOUR_h^{femaq} - LZFQ_h - \frac{CTH_h - \sum_{ij} [PC_{ij} C_{ij}^{min}]}{[WZFNQ_h (1 - z_h^{femnq} - z_h^{malnq} - z_h^{femaq} - z_h^{malq} - z_h^{hom})]} \\
98. & LSHNQ_h = MAXHOUR_h^{malnq} - LZHNQ_h - \frac{CTH_h - \sum_{ij} [PC_{ij} C_{ij}^{min}]}{[WZHNQ_h (1 - z_h^{femnq} - z_h^{malnq} - z_h^{femaq} - z_h^{malq} - z_h^{hom})]} \\
99. & LSHQ_h = MAXHOUR_h^{malq} - LZHQ_h - \frac{CTH_h - \sum_{ij} [PC_{ij} C_{ij}^{min}]}{[WZHNQ_h (1 - z_h^{femnq} - z_h^{malnq} - z_h^{femaq} - z_h^{malq} - z_h^{hom})]} \\
100. & \sum_h LSHNQ_h = \sum_j LHNQ_j \\
101. & \sum_h LSFNQ_h = \sum_j LFNQ_j \\
102. & \sum_h LSFQ_h = \sum_j LFQ_j \\
103. & \sum_h LSHQ_h = \sum_j LHQ_j \\
104. & \sum_j KD_{k,j} = KS_j \\
105. & IT = \sum_h SH_h + \sum_f SF_f + SG + SROW \\
106. & \sum_j DS_{j,i} = DD_i \\
107. & \sum_j EX_{j,i} = EXD_i
\end{aligned}$$

Gross domestic product

$$\begin{aligned}
108. & GDP^{BP} = \sum_j PVA_j VA_j + TIPT \\
109. & GDP^{MP} = GDP^{BP} + TPRCTS \\
110. & GDP^{IB} = \sum_j [Wf q LSFQ_h + Whq LSHQ_h + Wfnq LSFNQ_h + Whnq LSHNQ_h] + \sum_{k,j} R_{k,j} KD_{k,j} + TPROD_n + TPRCTS \\
111. & GDP^{FD} = \sum_i PC_i [C_i + CG_i + INV_i] + \sum_i PE_i^{FOB} EXD_i - e \sum_i PWM_i IM_i
\end{aligned}$$

Real variables

$$\begin{aligned}
112. & CTH^{REAL} = \frac{CTH_h}{G} \\
113. & G^{REAL} = \frac{PIXCON}{PIXGVT} \\
114. & GDP^{BP_REAL} = \frac{GDP^{BP}}{GDB^{MP}} \\
115. & GDP^{MP_REAL} = \frac{PIXGDP}{GDB^{MP}} \\
116. & GFCF^{REAL} = \frac{PIXCON}{PIXINV}
\end{aligned}$$

Home production and consumption

$$\begin{aligned}
117. & Z_h = B_h^{zlab} \left[\beta_h^{zlab} LZFNQ_h^{-\rho_h^{zlab}} + (1 - \beta_h^{zlab}) LZHNQ_h^{-\rho_h^{zlab}} \right]^{-1/\rho_h^{zlab}} \\
118. & LZFNQ_h = \left\{ \left[\frac{\beta_h^{zlab}}{(1 - \beta_h^{zlab})} \right] \left[\frac{WZHNQ_h}{WZFNQ_h} \right]^{\sigma_h^{zlab}} \right\} LZHNQ_h \\
119. & LZFNQ_h = B_h^{zlabf} \left[\beta_h^{zlabf} LZFNQ_h^{-\rho_h^{zlabf}} + (1 - \beta_h^{zlabf}) LZHNQ_h^{-\rho_h^{zlabf}} \right]^{-1/\rho_h^{zlabf}} \\
120. & LZFNQ_h = \left\{ \left[\frac{\beta_h^{zlabf}}{(1 - \beta_h^{zlabf})} \right] \left[\frac{WZFNQ_h}{WZFNQ_h} \right]^{\sigma_h^{zlabf}} \right\} LZFNQ_h \\
121. & LZHNQ_h = B_h^{zlabh} \left[\beta_h^{zlabh} LZHNQ_h^{-\rho_h^{zlabh}} + (1 - \beta_h^{zlabh}) LZHNQ_h^{-\rho_h^{zlabh}} \right]^{-1/\rho_h^{zlabh}} \\
122. & LZHNQ_h = \left\{ \left[\frac{\beta_h^{zlabh}}{(1 - \beta_h^{zlabh})} \right] \left[\frac{WZHNQ_h}{WZHNQ_h} \right]^{\sigma_h^{zlabh}} \right\} LZHNQ_h \\
123. & P_h^{hom} = \frac{WZFNQ_h LZFNQ_h + WZHNQ_h LZHNQ_h}{Z_h} \\
124. & WZFNQ_h = \frac{WZFNQ_h LZFNQ_h + WZFNQ_h LZFNQ_h}{LZFNQ_h} \\
125. & WZHNQ_h = \frac{WZHNQ_h LZHNQ_h + WZHNQ_h LZHNQ_h}{LZHNQ_h} \\
126. & CZ_h = Z_h
\end{aligned}$$

Appendix A.2-1 : Annexe du Chapitre 2

S.1. Institutional desegregation and model sets

All industries (26)

$i, ij \in J = \{a_trad1, a_trad2, a_trad3, a_live1, a_live2, a_live3, a_mod1, a_mod2, a_mod3, a_forfish, a_hydro, a_min, a_food, a_bever, a_text, a_paper, a_fuel, a_mach, a_utilit, a_const, a_trade, a_trans, a_finserv, a_comserv, a_hotdom, a_pubserv\}$

a_trad1: Traditional agriculture - Highlands
a_trad2: Traditional agriculture - Highlands
a_trad3: Traditional agriculture - Highlands
a_live1: Livestock - Highlands
a_live2: Livestock - Valleys
a_live3: Livestock - Valleys
a_mod1: Modern agriculture - Highlands
a_mod2: Modern agriculture - Highlands
a_mod3: Modern agriculture - Highlands
a_forfish: Forestry & fishing
a_hydro: Hydrocarbons
a_min: Mining
a_food: Food processing
a_bever: Beverages and tobacco
a_text: Textiles
a_paper: Paper and wood
a_fuel: Refined oil products
a_mach: Machinery and metal products
a_utilit: Electricity gas and water
a_const: Construction
a_trade: Commerce
a_trans: Transportation
a_finserv: Financial services
a_comserv: Social services
a_hotdome: Restaurants & hotels
a_pubserv: Public administration

All commodities (30)

$i, ij \in I = \{c_cer, c_veg, c_root, c_fruit, c_otniag, c_oilsee, c_sucan, c_coca, c_live, c_forfish, c_hydro, c_min, c_meat, c_milk, c_flour, c_sugar, c_othfood, c_bever, c_text, c_paper, c_fuel, c_mach, c_utilit, c_const, c_trade, c_trans, c_finserv, c_comserv, c_hotdom, c_pubserv\}$

c_cer: Cereals
c_veg: Vegetables
c_root: Root crops
c_fruit: Fruits
c_otniag: Other non-industrial agriculture
c_oilsee: Soybeans
c_sucan: Sugarcane
c_coca: Coca
c_live: Livestock
c_forfish: Forestry and fishing
c_hydro: Hydrocarbons
c_min: Mining
c_meat: Meat processing
c_milk: Dairy products
c_flour: Bakery
c_sugar: Sugar & confectionary
c_othfood: Other food processing
c_bever: Beverages and tobacco
c_text: Textiles
c_paper: Paper and wood
c_fuel: Refined oil products
c_mach: Machinery and metal products
c_utilit: Electricity gas and water
c_const: Construction
c_trade: Commerce
c_trans: Transportation
c_finserv: Financial services
c_comserv: Social services
c_hotdom: Restaurants & hotels
c_pubserv: Public administration

Agents (9)

Non-governmental agent: $\{gvt\}$

Rest of the world: $\{row\}$

Firms: $\{f\}$

Households:

$\{hh1m, hh1f, hh2m, hh2f, hh3m, hh3f\}$

hh1m: Male headed household highlands

hh1f: Female headed household highlands

hh2m: Male headed household valleys

hh2f: Female headed household valleys

hh3m: Male headed household lowlands

hh3f: Female headed household lowlands

Production factors (8)

Labour categories: $l \in L =$

$\{USKM, USKF, SKLM, SKLF\}$

USKH: Unskilled workers male

SKLH: Skilled workers male

USKF: Unskilled workers female

SKLF: Skilled workers female

Capital categories: $k \in K =$

$\{CAP, LND1, LND2, LND3\}$

CAP: Capital,

LND1: Land highlands

LND2: Land lowlands

LND3: Land valleys

S.2. List of variables and parameters

Volume variables

$C_{i,h}$:	Consumption of commodity i by type h households
$C_{i,h}^{MIN}$:	Minimum consumption of commodity i by type h households
CG_i :	Public consumption of commodity i
CI_j :	Total intermediate consumption of industry j
CTH_h^{REAL} :	Real consumption expenditures of household h
DD_i :	Domestic demand for commodity i produced locally
$DI_{i,j}$:	Intermediate consumption of commodity i by industry j
DIT_i :	Total intermediate demand for commodity i
$DS_{j,i}$:	Supply of commodity i by sector j to the domestic market
$EX_{j,i}$:	Quantity of product i exported by sector j
EXD_i :	World demand for exports of product i
G^{REAL} :	Real government expenditures
$GDP^{BP,REAL}$:	Real GDP at basic prices
$GDP^{MP,REAL}$:	Real GDP at market prices
$GFCF^{REAL}$:	Real gross fixed capital formation
IM_i :	Quantity of product i imported
INV_i :	Final demand of commodity i for investment purposes (GFCF)
KDC_j :	Industry j demand for composite capital
LHQ_j :	Industry j demand for male skilled labour
LFQ_j :	Industry j demand for female skilled labour
$LHNQ_j$:	Industry j demand for male unskilled labour
$LFNQ_j$:	Industry j demand for female unskilled labour
LQ_j :	Industry j demand for skilled labour
LNQ_j :	Industry j demand for unskilled labour
LDC_j :	Industry j demand for composite labour

$MRGN_i$:	Demand for commodity i as a trade or transport margin
Q_i :	Quantity demanded of composite commodity i
VA_j :	Value added of industry j
$XS_{j,i}$:	Industry j production of commodity i
XST_j :	Total aggregate output of industry j

Home production and Labour supply variables

P_h^{HOM} :	Purchase price of home-produced commodities by type h households
CZ_h :	Consumption of home-produced commodities by type h households
Z_h :	Home production for each type of household
$LSFNQ_h$:	Household H female unskilled market labour supply
$LSHNQ_h$:	Household H male unskilled market labour supply
$LSFQ_h$:	Household H female skilled market labour supply
$LSHQ_h$:	Household H male skilled market labour supply
$LZHNQ_h$:	Household H male unskilled time used to produce home commodities
$LZFNQ_h$:	Household H female unskilled time used to produce home commodities
$LZHQ_h$:	Household H male skilled time used to produce home commodities
$LZFQ_h$:	Household H female skilled time used to produce home commodities
LZH_h :	Household H male time used to produce home commodities
LZF_h :	Household H female time used to produce home commodities

Price variables

$P_{j,i}$:	Basic price of industry j's production of commodity i
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<i>TIKT:</i>	Total government revenue from taxes on capital
<i>TIM_i:</i>	Government revenue from import duties on product i
<i>TIMT:</i>	Total government revenue from import duties
<i>TIP_j:</i>	Government revenue from taxes on industry j production (excluding taxes directly related to the use of capital and labour)
<i>TIPT:</i>	Total government revenue from production taxes (excluding taxes directly related to the use of capital and labour)
<i>TIW_{l,j}:</i>	Government revenue from payroll taxes on type l labour in industry j
<i>TIWT:</i>	Total government revenue from payroll taxes
<i>TIX_i:</i>	Government revenue from export taxes on product i
<i>TIXT:</i>	Total government revenue from export taxes
<i>TPRCTS:</i>	Total government revenue from taxes on products and imports
<i>TPRODN:</i>	Total government revenue from other taxes on production
<i>TR_{ag,agj}:</i>	Transfers from agent agj to agent ag
<i>YDF_f:</i>	Disposable income of type f businesses
<i>YDH_h:</i>	Disposable income of type h households
<i>YF_f:</i>	Total income of type f businesses
<i>YFK_f:</i>	Capital income of type f businesses
<i>YFTR_f:</i>	Transfer income of type f businesses
<i>YG:</i>	Total government income
<i>YGK:</i>	Government capital income
<i>YGTR:</i>	Government transfer income
<i>YH_h:</i>	Total income of type h households
<i>YHK_h:</i>	Capital income of type h households
<i>YHL_h:</i>	Labour income of type h households
<i>YHTR_h:</i>	Transfer income of type h households
<i>YROW:</i>	Rest-of-the-world income

Exogenous variables and closures

<i>G:</i>	Current government expenditures on goods and services
<i>KD_{k,j}:</i>	Demand for type k capital by industry j
<i>KS_k:</i>	Supply of type k capital
<i>VSTK_i:</i>	Inventory change of commodity i
<i>CZ_{i,h}^{MIN}:</i>	Minimum consumption of home-produced commodities (LES consumption function)
<i>CAB:</i>	Current account balance
<i>PWM_i:</i>	World price of imported product i (expressed in foreign currency)
<i>PWX_i:</i>	World price of exported product i (expressed in foreign currency)
<i>e:</i>	Exchange rate (price of foreign currency in local currency)

Rates and intercepts

<i>sh0_h:</i>	Intercept (type h household savings)
<i>sh1_h:</i>	Slope (type h household savings)
<i>tr0_h:</i>	Intercept (transfers by type h households to government)
<i>tr1_h:</i>	Marginal rate of transfers by type h households to government
<i>ttdf0:</i>	Intercept (income taxes of type f businesses)
<i>ttdf1:</i>	Marginal income tax rate of type f businesses
<i>ttdh0_h:</i>	Intercept (income taxes of type h households)
<i>ttdh1_h:</i>	Marginal income tax rate of type h households
<i>ttic_i:</i>	Tax rate on commodity i
<i>ttik_{k,j}:</i>	Tax rate on type k capital used in industry j
<i>ttim_i:</i>	Rate of taxes and duties on imports of commodity i
<i>ttip_j:</i>	Tax rate on the production of industry j
<i>ttiw_{l,j}:</i>	Tax rate on type l worker compensation in industry j
<i>ttix_i:</i>	Export tax rate on exported commodity i

Parameters linked to labour market and home-production

$MAXHOUR_h^{malnq}$: Maximum time available for unskilled male in household h

$MAXHOUR_h^{malq}$: Maximum time available for skilled male in household h

$MAXHOUR_h^{femnq}$: Maximum time available for unskilled female in household h

$MAXHOUR_h^{femq}$: Maximum time available for skilled female in household h

Z_h^{femnq} : Household H's share of unskilled female home consumption

Z_h^{femq} : Household H's share of skilled female home consumption

Z_h^{malnq} : Household H's share of unskilled male home consumption

Z_h^{malq} : Household H's share of skilled male home consumption

Z_h^{hom} : Household H's share of home consumption

$LELAS_h^{femnq}$: Household H's elasticity of unskilled female labour supply with respect to income

$LELAS_h^{femq}$: Household H's elasticity of skilled female labour supply with respect to income

$LELAS_h^{malnq}$: Household H's elasticity of unskilled male labour supply with respect to income

$LELAS_h^{malq}$: Household H's elasticity of skilled male labour supply with respect to income

Ψ_h^{hom} : Consumption elasticity of household goods

$\gamma_{i,h}^{LES}$: Marginal share of commodity i in household h consumption budget

Ψ_h^{hom} : Consumption elasticity of household goods

B_h^{zlab} : Scale parameter (CES – composite home production)

B_h^{zlabh} : Scale parameter (CES – male home production)

B_h^{zlabf} : Scale parameter (CES – female home production)

β_h^{zlab} : Share parameter (CES – composite home production)

β_h^{zlabh} : Share parameter (CES – male home production)

β_h^{zlabf} : Share parameter (CES – female home production)

ρ_h^{zlab} : Elasticity parameter (CES – composite home production)

ρ_h^{zlabh} : Elasticity parameter (CES – male home production)

ρ_h^{zlabf} : Elasticity parameter (CES – female home production)

σ_h^{zlab} : Elasticity (CES – composite home production)

σ_h^{zlabh} : Elasticity (CES – male home production)

σ_h^{zlabf} : Elasticity (CES – female home production)

B_j^{LDC} : Scale parameter (CES – composite labour)

B_j^{LQ} : Scale parameter (CES – Skilled labour)

B_j^{LNQ} : Scale parameter (CES – unskilled labour)

β_j^{LDC} : Share parameter (CES – composite labour)

β_j^{LQ} : Share parameter (CES – Skilled labour)

β_j^{LNQ} : Share parameter (CES – unskilled labour)

ρ_j^{LDC} : Elasticity parameter (CES – composite labour)

ρ_j^{LQ} : Elasticity parameter (CES – Skilled labour)

ρ_j^{LNQ} : Elasticity parameter (CES – Unskilled labour)

σ_j^{LDC} : Elasticity (CES – Skilled labour)

σ_j^{LQ} : Elasticity (CES – Skilled labour)

σ_j^{LNQ} : Elasticity (CES – unskilled labour)

Other parameters

$ai_{i,j}$: Input-output coefficient

B_j^{KD} : Scale parameter (CES – composite capital)

B_j^{VA} :	Scale parameter (CES - value added)	ρ_i^M :	Elasticity parameter (CES - composite commodity)
$B_{j,i}^X$:	Scale parameter (CET - exports and local sales)	ρ_j^{VA} :	Elasticity parameter (CES - value added)
B_j^{XT} :	Scale parameter (CET - total output)	$\rho_{j,i}^X$:	Elasticity parameter (CET - exports and local sales)
$\beta_{k,j}^{KD}$:	Share parameter (CES - composite capital)	ρ_j^{XT} :	Elasticity parameter (CET - total output)
β_i^M :	Scale parameter (CES - composite commodity)	σ_j^{KD} :	Elasticity (CES - composite capital)
β_j^{VA} :	Share parameter (CES - value added)	σ_i^M :	Elasticity (CES - composite commodity)
$\beta_{j,i}^X$:	Share parameter (CET - exports and local sales)	σ_j^{VA} :	Elasticity (CES - value added)
$\beta_{j,i}^{XT}$:	Share parameter (CET - total output)	$\sigma_{j,i}^X$:	Elasticity (CET - exports and local sales)
η :	Price elasticity of indexed transfers and parameters	σ_j^{XT} :	Elasticity (CET - total output)
$frish_h$:	Frisch parameter (LES function)	σ_i^{XD} :	Price elasticity of the world demand for exports of product i
γ_i^{GVT} :	Share of commodity i in total current public expenditures on goods and services	$\sigma_{i,h}^Y$:	Income elasticity of consumption
γ_i^{INV} :	Share of commodity i in total investment expenditures	$tmrg_{i,ij}$:	Rate of margin i applied to commodity ij
i_{oj} :	Coefficient (Leontief - intermediate consumption)	$tmrg_{i,ij}^X$:	Rate of margin i applied to exported commodity i
K^{MOB} :	Flag parameter (1 if capital is mobile)	v_j :	Coefficient (Leontief - value added)
$\lambda_{ag,k}^{RK}$:	Share of type k capital income received by agent ag		
$\lambda_{ag,agj}^{TR}$:	Share parameter (transfer functions)		
λ_h^{wmnq} :	Share of male unskilled labour income received by type h households		
λ_h^{wfnq} :	Share of female unskilled labour income received by type h households		
λ_h^{wmq} :	Share of male skilled labour income received by type h households		
λ_h^{wfnq} :	Share of female skilled labour income received by type h households		
ρ_j^{KD} :	Elasticity parameter (CES - composite capital)		

S.3. Model equations

Production

1. $VA_j = v_j XST_j$
2. $Cl_j = i_{0j} XST_j$
3. $VA_j = B_j^{VA} \left[\beta_j^{VA} LD_j^{-\rho_j^{VA}} + (1 - \beta_j^{VA}) KD_j^{-\rho_j^{VA}} \right]^{-\frac{1}{\rho_j^{VA}}}$
4. $LDC_j = \left\{ \left[\frac{\beta_j^{VA}}{(1 - \beta_j^{VA})} \right] \left[\frac{RC_j}{WC_j} \right] \right\}^{\sigma_j^{VA}} KDC_j$
5. $LDC_j = B_j^{LDC} \left[\beta_j^{LDC} LQ_j^{-\rho_j^{LDC}} + (1 - \beta_j^{LDC}) LNQ_j^{-\rho_j^{LDC}} \right]^{-1/\rho_j^{LDC}}$
6. $LQ_j = \left\{ \left[\frac{\beta_j^{LDC}}{(1 - \beta_j^{LDC})} \right] \left[\frac{WNQ_j}{WQ_j} \right] \right\}^{\sigma_j^{LDC}} LNQ_j$
7. $LQ_j = B_j^{LQ} \left[\beta_j^{LQ} LHQ_j^{-\rho_j^{LQ}} + (1 - \beta_j^{LQ}) LFQ_j^{-\rho_j^{LQ}} \right]^{-1/\rho_j^{LQ}}$
8. $LHQ_j = \left\{ \left[\frac{\beta_j^{LQ}}{(1 - \beta_j^{LQ})} \right] \left[\frac{WFQ_j}{WHQ_j} \right] \right\}^{\sigma_j^{LQ}} LFQ_j$
9. $LNQ_j = B_j^{LNQ} \left[\beta_j^{LNQ} LHNQ_j^{-\rho_j^{LNQ}} + (1 - \beta_j^{LNQ}) LFNQ_j^{-\rho_j^{LNQ}} \right]^{-1/\rho_j^{LNQ}}$
10. $LHNQ_j = \left\{ \left[\frac{\beta_j^{LNQ}}{(1 - \beta_j^{LNQ})} \right] \left[\frac{WFNQ_j}{WHNQ_j} \right] \right\}^{\sigma_j^{LNQ}} LFNQ_j$
11. $KDC_j = B_j^{KDC} \left[\sum_k \beta_j^{KDC} KD_{k,j}^{-\sigma_j^{KDC}} \right]^{-1/\sigma_j^{KDC}}$
12. $KD_{k,j} = \left[\frac{\beta_j^{KDC} RC_j}{RT_{k,j}} \right] B_j^{KDC} (\sigma_j^{KDC} - 1) KDC_j$
13. $DI_{i,j} = ai_{i,j} Cl_j$

Income and Savings

Households

14. $YH_h = YHL_h + YHK_h + YHTR_h$
15. $YHL_h = Wfq LSFQ_h + Whq LSHQ_h + Wfnq LSFNQ_h + Whnq LSHNQ_h$
16. $YHK_h = \lambda_h^{RK} (\sum_j R_j KD_j)$
17. $YHTR_h = \sum_{ag} TR_{h,ag}$
18. $YDH_h = YH_h - TDH_h - TR_{gvt,h}$
19. $CTH_h = YDH_h - SH_h - \sum_{agng} TR_{agng,h}$
20. $SH_h = PIXCON^N SH_0_h + SH_1_h YDH_h$

Firms

21. $YF = YFK + YFTR$
22. $YFK = \sum_k \lambda_j^{RK} (\sum_j R_{k,j} KD_{k,j})$
23. $YFTR = \sum_{ag} TR_{f,ag}$
24. $YDF = YF - TDF$
25. $SF = YDF - \sum_{ag} TR_{ag,f}$

Government

26. $YG = YGK + TDHT + TDF + TPRODN + TPRCTS + YGTR$
27. $YGK = \lambda_{gvt}^{RK} (\sum_j R_j KD_j)$
28. $TDHT = \sum_h TDH_h$
29. $TDF = \sum_h TDF_f$
30. $TPRODN = TIWT + TIKT + TIPT$
31. $TIWT = \sum_{i,j} TIW_{i,j}$
32. $TIKT = \sum_{k,j} TIK_{k,j}$
33. $TIPT = \sum_j TIP_j$
34. $TPRCTS = TICT + TIMT + TIXT$
35. $TICT = \sum_i TIC_i$
36. $TIMT = \sum_i TIM_i$
37. $TIXT = \sum_i TIX_i$
38. $YGTR = \sum_{agng} TR_{gvt,agng}$
39. $TDH_h = PIXCON^N ttdh_0_h + ttdh_1_h YH_h$
40. $TDF_f = PIXCON^N ttdf_0_f + ttdf_1_f YFK_f$
41. $TIW_{i,j} = tw_{i,j} \{ Whnq LHNQ_j + Wfnq LFNQ_j + Whq LHQ_j + Wfq LFQ_j \}$
42. $TIK_{k,j} = tik_{k,j} R_{k,j} KD_{k,j}$

43. $TIP_j = ttip_j PP_j XST_j$
44. $TIC_i = tti_{i,j} \left[(PL_i + \sum_{ij} PC_{ij} tmr_{g_{ij,i}}) DD_i \left((1 + tti_{i,j}) PWM_i e + \sum_{ij} PC_{ij} tmr_{g_{ij,i}} \right) IM_i \right]$
45. $TIM_i = tti_{i,j} PWM_i e IM_i$
46. $TIX_i = tti_{i,j} (PE_i + \sum_{ij} PC_{ij} tmr_{g_{ij,i}}) EXD_i$
47. $SG = YG - \sum_{agng} TR_{agng,gvt} - G$

Rest of the world

48. $YROW = e \sum_i PWM_i IM_i + \lambda_{row}^{RK} (\sum_j R_j KD_j) + \sum_{agd} TR_{row,agd}$
49. $SROW = YROW - \sum_i PE_i^{FOB} EX_i - \sum_{agd} TR_{agd,row}$
50. $SROW = -CAB$

Transfers

51. $TR_{agn,g,h} = \lambda_{agn,g,h}^{TR} YDH_h$
52. $TR_{gvt,h} = PIXCON^N tr_0_h tr_1_h YH_h$
53. $TR_{ag,f} = \lambda_{ag,f}^{TR} YDF_f$
54. $TR_{agn,gvt} = PIXCON^N TR_{agn,gvt}^0$
55. $TR_{agd,row} = PIXCON^N TR_{agd,row}^0$

Demand

56. $PC_i C_{i,h} = PC_i C_{i,h}^{MIN} + \left(\frac{Y_{i,h}^{LES}}{(1 - z_h^{femng} - z_h^{matna} - z_h^{fema} - z_h^{mala} - z_h^{hom})} \right) (CTH_h - \sum_{ij} PC_{ij} C_{ij,h}^{MIN})$
57. $CZ_h P_h^{hom} = CZ_{i,h} P_h^{hom} + \left(\frac{z_h^{hom}}{(1 - z_h^{femng} - z_h^{matna} - z_h^{fema} - z_h^{mala} - z_h^{hom})} \right) (CTH_h - \sum_{ij} PC_{ij} C_{ij,h}^{MIN})$
58. $GFCF = IT - \sum_i PC_i VSTK_i$
59. $PC_i INV_i = Y_i^{INV} GFCF$
60. $PC_i CG_i = Y_i^{GVT} G$
61. $DI_{i,j} = \sum_j DI_{i,j}$
62. $MRGN_i = \sum_{ij} tmr_{g_{i,j}} DD_{ij} + \sum_{ij} tmr_{g_{i,j}} IM_{ij} + \sum_{ij} tmr_{g_{i,j}} EXD_{ij}$

International trade

63. $XST_j = B_j^{XT} \left[\sum_i \beta_{j,i}^{XT} X S_{j,i}^{\rho_j^{XT}} \right]^{-\frac{1}{\rho_j^{XT}}}$
64. $X S_{j,i} = \frac{XST_j}{(B_j^{XT})^{1 + \sigma_j^{XT}}} \left[\frac{P_{ji}}{\beta_{j,i}^{XT} P T_j} \right]^{\sigma_j^{XT}}$
65. $X S_{j,i} = B_j^X \left[\beta_{j,i}^X EX_{j,i}^{\rho_j^X} + (1 - \beta_{j,i}^X) DS_{j,i}^{\rho_j^X} \right]^{-\frac{1}{\rho_j^X}}$
66. $EX_{j,i} = \left[\frac{1 - \beta_{j,i}^X PE_i}{\beta_{j,i}^X PL_i} \right]^{\sigma_j^X} DS_{j,i}$
67. $EXD_i = EXD_i^0 \left(\frac{e PWX_i}{PE_i^{FOB}} \right)^{\sigma_i^{XD}}$
68. $Q_i = B_i^M \left[\beta_i^M IM_i^{-\rho_i^M} + (1 - \beta_i^M) DD_i^{-\rho_i^M} \right]^{-\frac{1}{\rho_i^M}}$
69. $IM_i = \left[\frac{\beta_i^M PD_i}{1 - \beta_i^M PM_i} \right]^{\sigma_i^M} DD_i$

Prices

70. $PP_j XST_j = PVA_j VA_j + PC_j Cl_j$
71. $PT_j = (1 + ttip_j) PP_j$
72. $PC_j Cl_j = \sum_i PC_i DI_{i,j}$
73. $PVA_j VA_j = WC_j LDC_j + RC_j KDC_j$
74. $WC_j = \frac{LQ_j WQ_j + LNQ_j WNQ_j}{LDC_j}$
75. $WQ_j = \frac{LHQ_j WHq + LFQ_j Wfq}{LQ_j}$
76. $WNQ_j = \frac{LHNQ_j Whnq + LFNQ_j Wfnq}{LNQ_j}$
77. $RT_{k,j} = R_{k,j} (1 + ttik_{k,j})$
78. $R_{k,j} = Rk_k$

$$\begin{aligned}
79. P_{j,i} &= PT_j \\
80. P_{j,i} &= \frac{PE_i EX_{j,i} + PL_i DS_{j,i}}{XS_{j,i}} \\
81. PE_i^{FOB} &= (PE_i + \sum_{ij} PC_{ij} tmr g_{ij,i}^x)(1 + ttix_i) \\
82. PD_i &= (1 + ttic_i)(PL_i + \sum_{ij} PC_{ij} tmr g_{ij,i}) \\
83. PM_i &= (1 + ttic_i)(1 + ttim_i) e PWM_i + \sum_{ij} PC_{ij} tmr g_{ij,i} \\
84. PC_i &= \frac{PM_i M_i + PD_i DD_i}{Q_i}
\end{aligned}$$

Price indexes

$$\begin{aligned}
85. PIXGDP &= \sqrt{\frac{\sum_i (PVA_j + \frac{TIPO}{VA_j}) VA_j^{\rho} AO_j \sum_i (PVA_j VA_j + TIPO)}{\sum_i (PVA_j^{\rho} VA_j^{\rho} + TIPO^{\rho}) \sum_i (PVA_j^{\rho} + \frac{TIPO^{\rho}}{VA_j^{\rho}}) VA_j}} \\
86. PIXCON &= \frac{\sum_i PC_i \sum_h C_{i,h}^O}{\sum_i PC_i^O \sum_h C_{i,h}^O} \\
87. PIXINV &= \prod_i \left(\frac{PC_i}{PC_i^O} \right)^{Y_i^{INV}} \\
88. PIXGVT &= \prod_i \left(\frac{PC_i}{PC_i^O} \right)^{Y_i^{GVT}}
\end{aligned}$$

Equilibrium and labour supply

$$\begin{aligned}
89. Q_i &= \sum_h C_{i,h} + CG_i + INV_i + VSTK_i + DIT_i + MRGN_i \\
90. WZHNQ_h &= \frac{Whnq LSHNQ_h}{LSHNQ_h} \\
91. WZHQ_h &= \frac{Whq LSHQ_h}{LSHQ_h} \\
92. WZFNQ_h &= \frac{Wfnq LSFNQ_h}{LSFNQ_h} \\
93. WZFQ_h &= \frac{Wfq LSFQ_h}{LSFQ_h} \\
94. LSFNQ_h &= MAXHOUR_h^{femna} - LZFNQ_h - \frac{z_h^{femna} CTH_h - \sum_{ij} [PC_{ij} C_{ij,h}^{min}]}{[WZFNQ_h (1 - z_h^{femna} - z_h^{malna} - z_h^{fema} - z_h^{malq} - z_h^{hom})]} \\
95. LSFQ_h &= MAXHOUR_h^{fema} - LZFQ_h - \frac{z_h^{fema} CTH_h - \sum_{ij} [PC_{ij} C_{ij,h}^{min}]}{[WZFNQ_h (1 - z_h^{femna} - z_h^{malna} - z_h^{fema} - z_h^{malq} - z_h^{hom})]} \\
96. LSHNQ_h &= MAXHOUR_h^{malna} - LZHNQ_h - \frac{z_h^{malna} CTH_h - \sum_{ij} [PC_{ij} C_{ij,h}^{min}]}{[WZHNQ_h (1 - z_h^{femna} - z_h^{malna} - z_h^{fema} - z_h^{malq} - z_h^{hom})]} \\
97. LSHQ_h &= MAXHOUR_h^{malq} - LZHQ_h - \frac{z_h^{malq} CTH_h - \sum_{ij} [PC_{ij} C_{ij,h}^{min}]}{[WZHNQ_h (1 - z_h^{femna} - z_h^{malna} - z_h^{fema} - z_h^{malq} - z_h^{hom})]} \\
98. \sum_h LSHNQ_h &= \sum_j LHNQ_j \\
99. \sum_h LSFNQ_h &= \sum_j LFNQ_j \\
100. \sum_h LSFQ_h &= \sum_j LFQ_j \\
101. \sum_h LSHQ_h &= \sum_j LHQ_j \\
102. \sum_j KD_{k,j} &= KS_j
\end{aligned}$$

$$\begin{aligned}
103. IT &= \sum_h SH_h + \sum_f SF_f + SG + SROW \\
104. \sum_j DS_{j,i} &= DD_i \\
105. \sum_j EX_{j,i} &= EXD_i \\
106. &
\end{aligned}$$

Gross domestic product

$$\begin{aligned}
107. GDP^{BP} &= \sum_j PVA_j VA_j + TIPT \\
108. GDP^{MP} &= GDP^{BP} + TPRCTS \\
109. GDP^{IB} &= \sum_j [Wfq LSFQ_h + Whq LSHQ_h + Wfnq LSFNQ_h + Whnq LSHNQ_h] + \sum_{k,j} R_{k,j} KD_{k,j} + TPROD + TPRCTS \\
110. GDP^{FD} &= \sum_i PC_i [C_i + CG_i + INV_i] + \sum_i PE_i^{FOB} EXD_i - e \sum_i PWM_i M_i
\end{aligned}$$

Real variables

$$\begin{aligned}
111. CTH_h^{REAL} &= \frac{CTH_h}{PIXCON} \\
112. G^{REAL} &= \frac{G}{PIXGVT} \\
113. GDP^{BP, REAL} &= \frac{GDP^{BP}}{PIXGDP} \\
114. GDP^{MP, REAL} &= \frac{GDP^{MP}}{GDP^{BP}} \\
115. GFCF^{REAL} &= \frac{GFCF}{PIXCON}
\end{aligned}$$

Home production and consumption

$$\begin{aligned}
116. Z_h &= B_h^{zlab} \left[\beta_h^{zlab} LZ F_h^{-\rho_h^{zlab}} + (1 - \beta_h^{zlab}) LZ H_h^{-\rho_h^{zlab}} \right]^{-1/\rho_h^{zlab}} \\
117. LZ F_h &= \left\{ \frac{\beta_h^{zlab}}{(1 - \beta_h^{zlab})} \right\} \frac{[WZ F_h]}{LZ H_h} \sigma_h^{zlab} \\
118. LZ F_h &= B_h^{zlabf} \left[\beta_h^{zlabf} LZ FQ_h^{-\rho_h^{zlabf}} + (1 - \beta_h^{zlabf}) LZ FNQ_h^{-\rho_h^{zlabf}} \right]^{-1/\rho_h^{zlabf}} \\
119. LZ FQ_h &= \left\{ \frac{\beta_h^{zlabf}}{(1 - \beta_h^{zlabf})} \right\} \frac{[WZ FNQ_h]}{[WZ FQ_h]} \sigma_h^{zlabf} LZ FNQ_h \\
120. LZ H_h &= B_h^{zlabh} \left[\beta_h^{zlabh} LZ HQ_h^{-\rho_h^{zlabh}} + (1 - \beta_h^{zlabh}) LZ HNQ_h^{-\rho_h^{zlabh}} \right]^{-1/\rho_h^{zlabh}} \\
121. LZ HQ_h &= \left\{ \frac{\beta_h^{zlabh}}{(1 - \beta_h^{zlabh})} \right\} \frac{[WZ HNQ_h]}{[WZ HQ_h]} \sigma_h^{zlabh} LZ HNQ_h \\
122. \rho_h^{hom} &= \frac{WZ F_h LZ F_h + WZ H_h LZ H_h}{Z_h} \\
123. WZ F_h &= \frac{WZ FNQ_h LZ FNQ_h + WZ FQ_h LZ FQ_h}{LZ F_h} \\
124. WZ H_h &= \frac{WZ HNQ_h LZ HNQ_h + WZ HQ_h LZ HQ_h}{LZ H_h} \\
125. CZ_h &= Z_h
\end{aligned}$$

Appendix A.2-2 : Calibration of the parameters (and variables) in the equations related to the home production.

As we explained in the main text, demand (for market commodities and home-produced commodities) and supply functions (labour supplies) are obtained from maximizing households utility under the constraint of their budget, the technology used in the production function for home-produced commodity and their time.

Equation 56

$$PC_i C_{i,h} = PC_i C_{i,h}^{MIN} + \left(\frac{\gamma_{i,h}^{LES}}{(1 - z_h^{femnq} - z_h^{malnq} - z_h^{femq} - z_h^{malq} - z_h^{hom})} \right) \left(CTH_h - \sum_{ij} PC_{ij} C_{ij,h}^{MIN} \right)$$

Equation 57

$$CZ_h P_h^{hom} = CZ_{i,h}^{MIN} P_h^{hom} + \left(\frac{z_h^{hom}}{(1 - z_h^{femnq} - z_h^{malnq} - z_h^{femq} - z_h^{malq} - z_h^{hom})} \right) \left(CTH_h - \sum_{ij} PC_{ij} C_{ij,h}^{MIN} \right)$$

Equation 94

$$LSFNQ_h = MAXHOUR_h^{femnq} - LZFNQ_h - z_h^{femnq} \frac{(CTH_h - \sum_{ij} C_{ij,h}^{MIN} PC_{ij})}{[WZFNQ_h(1 - z_h^{femnq} - z_h^{malnq} - z_h^{femq} - z_h^{malq} - z_h^{hom})]}$$

Equation 95

$$LSHNQ_h = MAXHOUR_h^{malnq} - LZHNQ_h - z_h^{malnq} \frac{(CTH_h - \sum_{ij} C_{ij,h}^{MIN} PC_{ij})}{[WZHNQ_h(1 - z_h^{femnq} - z_h^{malnq} - z_h^{femq} - z_h^{malq} - z_h^{hom})]}$$

Equation 96

$$LSFQ_h = MAXHOUR_h^{femq} - LZFN_h - z_h^{femq} \frac{(CTH_h - \sum_{ij} C_{ij,h}^{MIN} PC_{ij})}{[WZFNQ_h(1 - z_h^{femnq} - z_h^{malnq} - z_h^{femq} - z_h^{malq} - z_h^{hom})]}$$

Equation 97

$$LSHQ_h = MAXHOUR_h^{malq} - LZHQ_h - z_h^{malq} \frac{(CTH_h - \sum_{ij} C_{ij,h}^{MIN} PC_{ij})}{[WZHQ_h(1 - z_h^{femnq} - z_h^{malnq} - z_h^{femq} - z_h^{malq} - z_h^{hom})]}$$

In these equations, we can see that we have parameters we need to calibrate, specifically:

$z_h^{femnq}, z_h^{malnq}, z_h^{femq}, z_h^{malq}, z_h^{hom}$ and $CZ_{i,h}^{MIN}$

We do not have information on the maximum time available for work and leisure. As in Fofana et al (2003), we follow the approach of De Melo and Tarr (1992)¹¹ to derive this maximum time from the formula of elasticity of labour supply respect to income applied in equations of labour supply (equations 94 to 97).

$$LELAS_{l,h} = \frac{z_{l,h} CTH_h}{(1 - \sum_l z_{l,h}) \cdot w_l LS_{l,h}}$$

The values of the elasticities are taken from the literature. Fofana et al (2003) used -0.2 for both men and women. We used -0.2 for unskilled men and women and -0.15 for skilled man and women. These values are the same as the one taken by Terra et al (2008). As the value of this parameter is important, we ran sensitivity analysis with extra values (low, very low, high and very high values).

From the equation above, we could derive the formula to compute the parameters $z_{l,h}$.

$$z_{l,h} = \frac{LS_{l,h} W_{l,h} LELAS_{l,h}}{(\sum LS_{l,h} W_{l,h} LELAS_{l,h} - CTHO_h)}$$

Finally, once we have calibrated the parameters $z_{l,h}$. we can calibrate the parameter z_h^{hom} by using the equation 57.

$$z_h^{hom} = \frac{\psi_h^{hom} PO_h^{hom} CZO_h (1 - \sum_l z_{l,h})}{\left[\psi_h^{hom} PO_h^{hom} CZO_h - \left(\frac{CZO_h}{FRISCH_h} \right) \right]}$$

Once the $z_{l,h}$ and z_h^{hom} are calibrated, we can compute $\gamma_{l,h}^{LES}$ from the equation 57.

We can check that the sum of all these parameters is equal to 1 (to respect the Engel law).

We then need to calibrate the total amount of time available for leisure and work. To this end, we need to compute the value of the minimum subsistence for the consumption of home commodity $CZ_{i,h}^{MIN}$.

Ψ_h^{hom} is the the share of the surplus of home commodity consumption in the total available. As in Fofana et al (2003), we took the value of 0.3 for this parameter. We ran a couple of sensitivity analysis to see whether the results were changing.

¹¹ De Melo, J. et Tarr, D. (1992), A General Equilibrium Analysis of US Foreign Trade Policy, The MIT Press.

$$CZ_{i,h}^{MIN} = (1 - \psi_h^{hom}) \cdot CZO_h$$

Then, we can compute the value of Maxhour (l,h) for each type of labour.

$$MAXHOUR_h^{femnq} = LSFNQ_h + LZFNQ_h + \frac{z_h^{femnq} (CTH_h - \sum_{ij} C_{ij,h}^{MIN} PC_{ij})}{[WFNQ_h (1 - z_h^{femnq} - z_h^{malnq} - z_h^{femq} - z_h^{malq} - z_h^{hom})]}$$

$$MAXHOUR_h^{malnq} = LSHNQ_h + LZHNQ_h + \frac{z_h^{malnq} (CTH_h - \sum_{ij} C_{ij,h}^{MIN} PC_{ij})}{[WZHNQ_h (1 - z_h^{femnq} - z_h^{malnq} - z_h^{femq} - z_h^{malq} - z_h^{hom})]}$$

$$MAXHOUR_h^{femq} = LSFQ_h + LZFN_h + \frac{z_h^{femq} (CTH_h - \sum_{ij} C_{ij,h}^{MIN} PC_{ij})}{[WZFNQ_h (1 - z_h^{femnq} - z_h^{malnq} - z_h^{femq} - z_h^{malq} - z_h^{hom})]}$$

$$MAXHOUR_h^{malq} = LSHQ_h + LZHQ_h + \frac{z_h^{malq} (CTH_h - \sum_{ij} C_{ij,h}^{MIN} PC_{ij})}{[WZHQ_h (1 - z_h^{femnq} - z_h^{malnq} - z_h^{femq} - z_h^{malq} - z_h^{hom})]}$$

Appendix A.3 : Annexe du Chapitre 3

S.1. Institutional desegregation and model sets

All industries (20)

$i, ij \in J = \{a_agr1, a_agr2, a_agr3, a_forfish, a_hydro, a_min, a_food, a_bever, a_text, a_paper, a_fuel, a_mach, a_utilit, a_const, a_trade, a_trans, a_finserv, a_comserv, a_hotdom, a_pubserv\}$

a_agr1:	Agriculture - Highlands
a_agr2:	Agriculture - Valleys
a_agr3:	Agriculture - Lowlands
a_forfish:	Forestry & fishing
a_hydro:	Hydrocarbons
a_min:	Mining
a_food:	Food processing
a_bever:	Beverages and tobacco
a_text:	Textiles
a_paper:	Paper and wood
a_fuel:	Refined oil products
a_mach:	Machinery and metal products
a_utilit:	Electricity gas and water
a_const:	Construction
a_trade:	Commerce
a_trans:	Transportation
a_finserv:	Financial services
a_comserv:	Social services
a_hotdome:	Restaurants & hotels
a_pubserv:	Public administration

All commodities (30)

$i, ij \in I = \{c_cer, c_veg, c_root, c_fruit, c_otniag, c_oilsee, c_sucan, c_coca, c_live, c_forfish, c_hydro, c_min, c_meat, c_milk, c_flour, c_sugar, c_othfood, c_bever, c_text, c_paper, c_fuel, c_mach, c_utilit, c_const, c_trade, c_trans, c_finserv, c_comserv, c_hotdom, c_pubserv\}$

c_cer:	Cereals
c_veg:	Vegetables
c_root:	Root crops
c_fruit:	Fruits

c_otniag:	Other non-industrial agriculture
c_oilsee:	Soybeans
c_sucan:	Sugarcane
c_coca:	Coca
c_live:	Livestock
c_forfish:	Forestry and fishing
c_hydro:	Hydrocarbons
c_min:	Mining
c_meat:	Meat processing
c_milk:	Dairy products
c_flour:	Bakery
c_sugar:	Sugar & confectionary
c_othfood:	Other food processing
c_bever:	Beverages and tobacco
c_text:	Textiles
c_paper:	Paper and wood
c_fuel:	Refined oil products
c_mach:	Machinery and metal products
c_utilit:	Electricity gas and water
c_const:	Construction
c_trade:	Commerce
c_trans:	Transportation
c_finserv:	Financial services
c_comserv:	Social services
c_hotdom:	Restaurants & hotels
c_pubserv:	Public administration

Agents (7)

Non-governmental agent (1):

{gvt}

Rest of the world (1):

{row}

Firms (1):

{f}

Households (4):

{hhrh, hhrf, hhuh, hhuf}

hhrh: Rural male headed household

hhuf: Rural female headed household

hhuh: Urban male headed household

hhuf: Urban female headed household

Production factors (10)

Labour categories:

$l \in L =$
 $\{USKM, USKF, SEKM, SEKF, SKLM, SKLF\}$
(6)

USKH: Unskilled workers male
SEKH: Semi-skilled workers male
SKLH: Skilled workers male
USKF: Unskilled workers female
SEKF: Semi-skilled workers female
SKLF: Skilled workers female

Capital categories:

$k \in K = \{CAP, LND1, LND2, LND3\}$ (4)

CAP: Capital,
LND1: Land highlands
LND2: Land lowlands
LND3: Land valleys

S.2. List of variables and parameters

Volume variables

$C_{i,h}$:	Consumption of commodity i by type h households	LDC_j :	Industry j demand for composite labor
$C_{i,h}^{MIN}$:	Minimum consumption of commodity i by type h households	LHQ_j :	Industry j demand for male skilled labour
CG_i :	Public consumption of commodity i	LFQ_j :	Industry j demand for female skilled labour
CI_j :	Total intermediate consumption of industry j	$LHMQ_j$:	Industry j demand for male semi-skilled labour
CTH_h^{REAL} :	Real consumption expenditures of household h	$LFMQ_j$:	Industry j demand for female semi-skilled labour
DD_i :	Domestic demand for commodity i produced locally	$LHNQ_j$:	Industry j demand for male unskilled labour
$DI_{i,j}$:	Intermediate consumption of commodity i by industry j	$LFNQ_j$:	Industry j demand for female unskilled labour
DIT_i :	Total intermediate demand for commodity i	LQ_j :	Industry j demand for skilled labour
$DS_{j,i}$:	Supply of commodity i by sector j to the domestic market	LMQ_j :	Industry j demand for semi-skilled labour
$EX_{j,i}$:	Quantity of product i exported by sector j	LNQ_j :	Industry j demand for unskilled labour
EXD_i :	World demand for exports of product i	$LSHQ_j$:	Supply of skilled male workers
G^{REAL} :	Real government expenditures	$LSFQ_j$:	Supply of skilled female workers
$GDP^{BP,REAL}$:	Real GDP at basic prices	$LSHMQ_j$:	Supply of semi-skilled male workers
$GDP^{MP,REAL}$:	Real GDP at market prices	$LSFMQ_j$:	Supply of semi-skilled female workers
$GFCF^{PRI,REAL}$:	Real private gross fixed capital formation	$LSHNQ_j$:	Supply of unskilled male workers
$GFCF^{PUB,REAL}$:	Real public gross fixed capital formation	$LSFNQ_j$:	Supply of unskilled female workers
IM_i :	Quantity of product i imported	$MGRN_i$:	Demand for commodity i as a trade or transport margin
$IND_{k,j}$:	Volume of new type k capital investment to industry j	Q_i :	Quantity demanded of composite commodity i
$IND_DAM_{k,j}$:	Volume d'investissement de nouveau type de capital public	VA_j :	Value added of industry j
INV_i :	Final demand of commodity i for investment purposes (GFCF)	$VSTK_i$:	Inventory change of commodity i
INV_PRI_i :	Final demand of commodity i for private investment purposes	$XS_{j,i}$:	Industry j production of commodity i
INV_PUB_i :	Final demand of commodity i for public investment purposes	XST_j :	Total aggregate output of industry j
$KD_{k,j}$:	Demand for type k capital by industry j		
KDC_j :	Industry j demand for composite capital		
KS_k :	Supply of type k capital		

Price variables

e :	Exchange rate (price of foreign currency in local currency)
IR :	Interest rate
$P_{j,i}$:	Basic price of industry j's production of commodity i
PC_i :	Purchaser price of composite commodity
PCI_j :	Intermediate consumption price index of industry j
PD_i :	Price of local product i sold on the domestic market (including all taxes and margins)
PE_i :	Price received for exported commodity i (excluding export taxes)
PE_i^{FOB} :	FOB price of exported commodity i (in local currency)
$PIXCON$:	Consumer price index
$PIXGDP$:	GDP deflator
$PIXGVT$:	Public expenditures price index
$PIXINV_PRI$:	Price of new private capital
$PIXINV_PUB$:	Price of new public capital
PL_i :	Price of local product i (excluding all taxes)
PM_i :	Price of imported product i (including all taxes and tariffs)
PP_j :	Industry j unit cost including taxes directly related to the use of capital and labour but excluding other taxes on production
PT_j :	Basic price of industry j's output
PVA_j :	Price of industry j value added (including taxes on production directly related to the use of capital and labour)
PWM_i :	World price of imported product i (expressed in foreign currency)
PWX_i :	World price of exported product i (expressed in foreign currency)
$R_{k,j}$:	Rental rate of type k capital in industry j
RC_j :	Rental rate of industry j composite capital
$RTI_{k,j}$:	Rental rate paid by industry j for type k capital including capital taxes

$U_{k,j}$:	User cost of type k capital in industry j
WQ_j :	Wage rate of industry j skilled labour
WMQ_j :	Wage rate of industry j semi-skilled labour
WNQ_j :	Wage rate of industry j unskilled labour
WC_j :	Wage rate of industry j composite labour
$WHNQ$:	Wage rate for male unskilled labour
$WFNQ$:	Wage rate for female unskilled labour
$WHMQ$:	Wage rate for male semi-skilled labour
$WFMQ$:	Wage rate for female semi-skilled labour
WHQ :	Wage rate for male skilled labour
WFQ :	Wage rate for female skilled labour

Nominal (value) variables

CAB :	Current account balance
CTH_h :	Consumption budget of type h households
G :	Current government expenditures on goods and services
GDP^{BP} :	GDP at basic prices
GDP^{FD} :	GDP at purchasers' prices from the perspective of final demand
GDP^{IB} :	GDP at market prices (income-based)
GDP^{MP} :	GDP at market prices
$GFCF$:	Gross fixed capital formation
IT :	Total investment expenditures
IT_PRI :	Total private investment expenditures
IT_PUB_TOT :	Total public investment expenditures
IT_PUB :	Investment budget for the public sector
IT_IDAM :	Public investment budget for non-public sectors
$DAMAG$:	Total destruction caused by disasters
$RKD_{k,h}$:	Type k capital income in industry j

SF :	Savings of type f businesses	YDH_h :	Disposable income of type h households
SG :	Government savings	YF_f :	Total income of type f businesses
SH_h :	Savings of type h households	YFK_f :	Capital income of type f businesses
$SROW$:	Rest-of-the-world savings	$YFTR_f$:	Transfer income of type f businesses
TDF_f :	Income taxes of type f businesses	YG :	Total government income
$TDFT$:	Total government revenue from business income taxes	YGK :	Government capital income
TDH_h :	Income taxes of type h households	$YGTR$:	Government transfer income
$TDHT$:	Total government revenue from household income taxes	YH_h :	Total income of type h households
TIC_i :	Government revenue from indirect taxes on product i	YHK_h :	Capital income of type h households
$TICT$:	Total government receipts of indirect taxes on commodities	YHL_h :	Labour income of type h households
$TIK_{k,j}$:	Government revenue from taxes on type k capital used by industry j	$YHTR_h$:	Transfer income of type h households
$TIKT$:	Total government revenue from taxes on capital	$YROW$:	Rest-of-the-world income
TIM_i :	Government revenue from import duties on product i	Rates and intercepts	
$TIMT$:	Total government revenue from import duties	$sh0_h$:	Intercept (type h household savings)
TIP_j :	Government revenue from taxes on industry j production (excluding taxes directly related to the use of capital and labour)	$sh1_h$:	Slope (type h household savings)
$TIPT$:	Total government revenue from production taxes (excluding taxes directly related to the use of capital and labour)	$tr0_h$:	Intercept (transfers by type h households to government)
$TIW_{l,j}$:	Government revenue from payroll taxes on type l labour in industry j	$tr1_h$:	Marginal rate of transfers by type h households to government
$TIWT$:	Total government revenue from payroll taxes	$ttdf0$:	Intercept (income taxes of type f businesses)
TIX_i :	Government revenue from export taxes on product i	$ttdf1$:	Marginal income tax rate of type f businesses
$TIXT$:	Total government revenue from export taxes	$ttdh0_h$:	Intercept (income taxes of type h households)
$TPRCTS$:	Total government revenue from taxes on products and imports	$ttdh1_h$:	Marginal income tax rate of type h households
$TPRODN$:	Total government revenue from other taxes on production	$ttic_i$:	Tax rate on commodity i
$TR_{ag,agj}$:	Transfers from agent agj to agent ag	$ttik_{k,j}$:	Tax rate on type k capital used in industry j
YDF_f :	Disposable income of type f businesses	$ttim_i$:	Rate of taxes and duties on imports of commodity i
		$ttip_j$:	Tax rate on the production of industry j
		$ttiwl_{l,j}$:	Tax rate on type l worker compensation in industry j
		$ttix_i$:	Export tax rate on exported commodity i

Parameters linked to labour market

B_j^{LDC} :	Scale parameter (CES - composite labour)
B_j^{LQ} :	Scale parameter (CES - Skilled labour)
B_j^{LMQ} :	Scale parameter (CES - Semi-skilled labour)
B_j^{LNQ} :	Scale parameter (CES - unskilled labour)
α_j^{LDC} :	Share parameter (CES - composite labour)
β_j^{LDC} :	Share parameter (CES - composite labour)
β_j^{LQ} :	Share parameter (CES - Skilled labour)
β_j^{LMQ} :	Share parameter (CES - Semi-skilled labour)
β_j^{LNQ} :	Share parameter (CES - unskilled labour)
ρ_j^{LDC} :	Elasticity parameter (CES - composite labour)
ρ_j^{LQ} :	Elasticity parameter (CES - Skilled labour)
ρ_j^{LMQ} :	Elasticity parameter (CES - Semi-skilled labour)
ρ_j^{LNQ} :	Elasticity parameter (CES - Unskilled labour)
σ_j^{LDC} :	Elasticity (CES - - Skilled labour)
σ_j^{LQ} :	Elasticity (CES - Skilled labour)
σ_j^{LMQ} :	Elasticity (CES - Semi-skilled labour)
σ_j^{LNQ} :	Elasticity (CES - unskilled labour)

Other parameters

$aij_{i,j}$:	Input-output coefficient
α :	Tobin q
A_{PRI}^K :	Scale parameter (private investment function)
A_{PUB}^K :	Scale parameter (public investment function)
B_j^{KD} :	Scale parameter (CES - composite capital)
B_i^M :	Scale parameter (CES - composite commodity)

B_j^{VA} :	Scale parameter (CES - value added)
$B_{j,i}^X$:	Scale parameter (CET - exports and local sales)
B_j^{XT} :	Scale parameter (CET - total output)
$\beta_{k,j}^{KD}$:	Share parameter (CES - composite capital)
β_i^M :	Scale parameter (CES - composite commodity)
β_j^{VA} :	Share parameter (CES - value added)
$\beta_{j,i}^X$:	Share parameter (CET - exports and local sales)
$\beta_{j,i}^{XT}$:	Share parameter (CET - total output)
η :	Price elasticity of indexed transfers and parameters
$frish_h$:	Frisch parameter (LES function)
γ_i^{GVT} :	Share of commodity i in total current public expenditures on goods and services
γ_i^{INVPRI} :	Share of commodity i in total private investment expenditures
γ_i^{INVPUB} :	Share of commodity i in total public investment expenditure
$\gamma_{i,h}^{LES}$:	Marginal share of commodity i in household h consumption budget
io_j :	Coefficient (Leontief - intermediate consumption)
$\lambda_{ag,k}^{RK}$:	Share of type k capital income received by agent ag
$\lambda_{ag,agj}^{TR}$:	Share parameter (transfer functions)
$\lambda_{h,l}^{WL}$:	SShare of type l labour income received by type h households
n :	Population growth rate
$n1$:	Population growth rate for the first period
$\varphi_{k,j}$:	Scale parameter (allocation of investment to industries)
pop :	Population index

ρ_j^{KD} :	Elasticity parameter (CES - composite capital)	σ_j^{VA} :	Elasticity (CES - value added)
ρ_i^M :	Elasticity parameter (CES - composite commodity)	$\sigma_{j,i}^X$:	Elasticity (CET - exports and local sales)
ρ_j^{VA} :	Elasticity parameter (CES - value added)	σ_j^{XT} :	Elasticity (CET - total output)
$\rho_{j,i}^X$:	Elasticity parameter (CET - exports and local sales)	σ_i^{XD} :	Price elasticity of the world demand for exports of product i
ρ_j^{XT} :	Elasticity parameter (CET - total output)	$\sigma_{i,h}^Y$:	Income elasticity of consumption
$\rho_{k,j}^{INV}$:	Elasticity (investment demand)	$tmrg_{i,ij}$:	Rate of margin i applied to commodity ij
σ_j^{KD} :	Elasticity (CES - composite capital)	$tmrg_{i,ij}^X$:	Rate of margin i applied to exported commodity i
σ_i^M :	Elasticity (CES - composite commodity)	v_j :	Coefficient (Leontief - value added)

S.3. Model equations

Production

1. $VA_j = v_j XST_j$
2. $Cl_j = i_{0j} XST_j$
3. $VA_j = B_j^{VA} \left[\beta_j^{VA} LD_j^{-\rho_j^{VA}} + (1 - \beta_j^{VA}) KD_j^{-\rho_j^{VA}} \right]^{-\frac{1}{\rho_j^{VA}}}$
4. $LDC_j = \left\{ \left[\frac{\beta_j^{VA}}{(1 - \beta_j^{VA})} \right] \left[\frac{RC_j}{WC_j} \right] \right\}^{\sigma_j^{VA}} KDC_j$
5. $LDC_j = B_j^{LDC} \left[\alpha_j^{LDC} LQ_j^{-\rho_j^{LDC}} + \beta_j^{LDC} LMQ_j^{-\rho_j^{LDC}} (1 - \alpha_j^{LDC} - \beta_j^{LDC}) LNQ_j^{-\rho_j^{LDC}} \right]^{-1/\rho_j^{LDC}}$
6. $LQ_j = \left\{ \left[\frac{\alpha_j^{LDC}}{(1 - \alpha_j^{LDC} - \beta_j^{LDC})} \right] \left[\frac{WNQ_j}{WQ_j} \right] \right\}^{\sigma_j^{LDC}} LNQ_j$
7. $LMQ_j = \left\{ \left[\frac{\beta_j^{LDC}}{(1 - \alpha_j^{LDC} - \beta_j^{LDC})} \right] \left[\frac{WMQ_j}{WMQ_j} \right] \right\}^{\sigma_j^{LDC}} LNQ_j$
8. $LQ_j = B_j^{LQ} \left[\beta_j^{LQ} LHQ_j^{-\rho_j^{LQ}} + (1 - \beta_j^{LQ}) LFQ_j^{-\rho_j^{LQ}} \right]^{-1/\rho_j^{LQ}}$
9. $LHQ_j = \left\{ \left[\frac{\beta_j^{LQ}}{(1 - \beta_j^{LQ})} \right] \left[\frac{WFQ_j}{WHQ_j} \right] \right\}^{\sigma_j^{LQ}} LFQ_j$
10. $LMQ_j = B_j^{LMQ} \left[\beta_j^{LMQ} LHMQ_j^{-\rho_j^{LMQ}} + (1 - \beta_j^{LMQ}) LFMQ_j^{-\rho_j^{LMQ}} \right]^{-1/\rho_j^{LMQ}}$
11. $LHMQ_j = \left\{ \left[\frac{\beta_j^{LMQ}}{(1 - \beta_j^{LMQ})} \right] \left[\frac{WFMQ_j}{WHMQ_j} \right] \right\}^{\sigma_j^{LMQ}} LFMQ_j$
12. $LNQ_j = B_j^{LNQ} \left[\beta_j^{LNQ} LHNQ_j^{-\rho_j^{LNQ}} + (1 - \beta_j^{LNQ}) LFNQ_j^{-\rho_j^{LNQ}} \right]^{-1/\rho_j^{LNQ}}$
13. $LHNQ_j = \left\{ \left[\frac{\beta_j^{LNQ}}{(1 - \beta_j^{LNQ})} \right] \left[\frac{WFNQ_j}{WHNQ_j} \right] \right\}^{\sigma_j^{LNQ}} LFNQ_j$
14. $KDC_j = B_j^{KD} \left[\sum_k \beta_j^{KD} KD_{k,j}^{-\sigma_j^{KD}} \right]^{-1/\sigma_j^{KD}}$
15. $KD_{k,j} = \left[\frac{\beta_j^{KD} RC_j}{RT_{k,j}} \right]^{\sigma_j^{KD}} B_j^{KD} (\sigma_j^{KD} - 1) KDC_j$
16. $DI_{i,j} = ai_{i,j} Cl_j$

Income and Savings

Households

17. $YH_h = YHL_h + YHK_h + YHTR_h$
18. $YHL_h = Wfq LSFQ_h + Whq LSHQ_h + Wfnq LSFNQ_h + Whnq LSHNQ_h$
19. $YHK_h = \lambda_h^{RK} (\sum_j R_j KD_j)$
20. $YHTR_h = \sum_{ag} TR_{h,ag}$
21. $YDH_h = YH_h - TDH_h - TR_{gvt,h}$
22. $CTH_h = YDH_h - SH_h - \sum_{agng} TR_{agng,h}$
23. $SH_h = PIXCON^n SH_0_h + SH_1_h YDH_h$

Firms

24. $YF = YFK + YFTR$
25. $YFK = \sum_k \lambda_f^{RK} (\sum_j R_{k,j} KD_{k,j})$
26. $YFTR = \sum_{ag} TR_{f,ag}$
27. $YDF = YF - TDF$
28. $SF = YDF - \sum_{ag} TR_{ag,f}$

Government

29. $YG = YGK + TDHT + TDF + TPRODn + TPRCTS + YGTR$
30. $YGK = \lambda_{gvt}^{RK} (\sum_j R_j KD_j)$
31. $TDHT = \sum_h TDH_h$
32. $TDF = \sum_h TDF_f$
33. $TPRODN = TIWT + TIKT + TIPT$
34. $TIWT = \sum_{l,j} TIW_{l,j}$
35. $TIKT = \sum_{k,j} TIK_{k,j}$
36. $TIPT = \sum_j TIP_j$
37. $TPRCTS = TICT + TIMT + TIXT$
38. $TICT = \sum_i TIC_i$
39. $TIMT = \sum_i TIM_i$
40. $TIXT = \sum_i TIX_i$
41. $YGTR = \sum_{agng} TR_{gvt,agng}$
42. $TDH_h = PIXCON^n ttdh0_h + ttdh1_h YH_h$
43. $TDF_f = PIXCON^n ttdf0_h + ttdh1_f YFK_f$
44. $TIW_{l,j} = ttw_{l,j} \{ Whnq LHNQ_j + Wfnq LFNQ_j + Whq LHQ_j + Wfq LFQ_j \}$
45. $TIK_{k,j} = ttik_{k,j} R_{k,j} KD_{k,j}$
46. $TIP_j = ttip_j P_j XST_j$
47. $TIC_i = ttic_i \left[(PL_i + \sum_{ij} PC_{ij} tmr_{g_{ij},i}) DD_i \left((1 + ttm_i) PWM_i e + \sum_{ij} PC_{ij} tmr_{g_{ij},i} IM_i \right) \right]$
48. $TIM_i = ttm_i PWM_i e IM_i$
49. $TIX_i = ttx_i (PE_i + \sum_{ij} PC_{ij} tmr_{g_{ij},i} EXD_i)$
50. $SG = YG - \sum_{agng} TR_{agng,gvt} - G$

Rest of the world

51. $YROW = e \sum_i PWM_i IM_i + \lambda_{row}^{RK} (\sum_j R_j KD_j) + \sum_{agd} TR_{row,agd}$
52. $SROW = YROW - \sum_i PE_i^{FOB} EX_i - \sum_{agd} TR_{agd,row}$
53. $SROW = -CAB$

Transfers

54. $TR_{agng,h} = \lambda_{agng,h}^{TR} YDH_h$
55. $TR_{gvt,h} = PIXCON^n tr0_h tr1_h YH_h$
56. $TR_{ag,f} = \lambda_{ag,f}^{TR} YDF_f$
57. $TR_{agng,gvt} = PIXCON^n TR_{agng,gvt}^0$
58. $TR_{agd,row} = PIXCON^n TR_{agd,row}^0$

Demand

59. $PC_i C_{i,h} = PC_i C_{i,h}^{MIN} + \gamma_{i,h}^{LES} (CTH_h - \sum_{ij} PC_{ij} C_{ij,h}^{MIN})$
60. $GFCF = IT - \sum_i PC_i VSTK_i$
61. $PC_i INV_PRI_i = \gamma_i^{INV_PRI} IT_PRI$
62. $PC_i INV_PUB_i = \gamma_i^{INV_PUB} IT_PUB_TOT$
63. $PC_i INV_i = INV_PRI_i + INV_PUB_i$
64. $PC_i CG_i = \gamma_i^{GVT} G$
65. $DIT_i = \sum_j DI_{i,j}$
66. $MRGN_i = \sum_{ij} tmr_{g_{ij},i} DD_{ij} + \sum_{ij} tmr_{g_{ij},i} IM_{ij} + \sum_{ij} tmr_{g_{ij},i} EXD_{ij}$

International trade

67. $XST_j = B_j^{XT} \left[\sum_i \beta_{j,i}^{XT} XS_{j,i}^{\rho_j^{XT}} \right]^{-\frac{1}{\rho_j^{XT}}}$
68. $XS_{j,i} = \frac{XST_j}{(B_j^{XT})^{1+\sigma_j^{XT}}} \left[\frac{P_{ji}}{\beta_{j,i}^{XT} PT_j} \right]^{\sigma_j^{XT}}$

$$69. X_{S_j,i} = B_{j,i}^X \left[\beta_{j,i}^X EX_{j,i}^X + (1 - \beta_{j,i}^X) DS_{j,i}^X \right]^{\frac{1}{\rho_j^X}}$$

$$70. EX_{j,i} = \left[\frac{1 - \beta_{j,i}^X PE_i}{\beta_{j,i}^X PL_i} \right]^{\sigma_j^X} DS_{j,i}$$

$$71. EXD_i = EXD_i^0 \left(\frac{e^{PW X_i}}{PE_i^{FOB}} \right)^{\sigma_i^{XD}}$$

$$72. Q_i = B_i^M \left[\beta_i^M IM_i^{-\rho_i^M} + (1 - \beta_i^M) DD_i^{-\rho_i^M} \right]^{\frac{-1}{\rho_i^M}}$$

$$73. IM_i = \left[\frac{\beta_i^M PD_i}{1 - \beta_i^M PM_i} \right]^{\sigma_i^M} DD_i$$

Prices

$$74. PP_j XST_j = PVA_j VA_j + PCI_j CI_j$$

$$75. PT_j = (1 + tti p_j) PP_j$$

$$76. PCI_j CI_j = \sum_i PC_i DI_{i,j}$$

$$77. PVA_j VA_j = WC_j LDC_j + RC_j KDC_j$$

$$78. WC_j = \frac{LQ_j WQ_j + LMQ_j WMQ_j + LNQ_j WNQ_j}{LDC_j}$$

$$79. WQ_j = \frac{LHQ_j Whq + LFQ_j Wfq}{LQ_j}$$

$$80. WMQ_j = \frac{LHMQ_j Whmq + LFMQ_j Wfmq}{LMQ_j}$$

$$81. WNQ_j = \frac{LHNQ_j Whnq + LFNQ_j Wfnq}{LNQ_j}$$

$$82. RT_{k,j} = R_{k,j} (1 + tti k_{k,j})$$

$$83. P_{j,i} = PT_j$$

$$84. P_{j,i} = \frac{PE_i EX_{j,i} + PL_i DS_{j,i}}{XS_{j,i}}$$

$$85. PE_i^{FOB} = (PE_i + \sum_{ij} PC_{ij} tmg_{ij,i}^X) (1 + tti x_i)$$

$$86. PD_i = (1 + tti c_i) (PL_i + \sum_{ij} PC_{ij} tmg_{ij,i})$$

$$87. PM_i = (1 + tti c_i) \left((1 + tti m_i) e^{PWM_i} + \sum_{ij} PC_{ij} tmg_{ij,i} \right)$$

$$88. PC_i = \frac{PM_i M_i + PD_i DD_i}{Q_i}$$

Price indexes

$$89. PIXGDP = \frac{\sum_j \left(\frac{PVA_j + TIP_j}{VA_j} \right) VA_j^0 AO_j \sum_j (PVA_j VA_j + TIP_j)}{\sum_j (PVA_j^0 VA_j^0 + TIP_j^0) \sum_j \left(\frac{PVA_j + TIP_j}{VA_j} \right) VA_j}$$

$$90. PIXCON = \frac{\sum_i PC_i \sum_h C_{i,h}^0}{\sum_i PC_i^0 \sum_h C_{i,h}^0}$$

$$91. PIXINV_PRI = \prod_i \left(\frac{PC_i}{PC_i^0} \right)^{Y_i^{INV_PRI}}$$

$$92. PIXINV_PUB = \prod_i \left(\frac{PC_i}{PC_i^0} \right)^{Y_i^{INV_PUB}}$$

$$93. PIXGVT = \prod_i \left(\frac{PC_i}{PC_i^0} \right)^{Y_i^{GVT}}$$

Equilibrium and labour supply

$$94. Q_i = \sum_h C_{i,h} + CG_i + INV_i + VSTK_i + DIT_i + MRGN_i$$

$$95. LSHNQ = \sum_j LHNQ_j$$

$$96. LSFNQ = \sum_j LFNQ_j$$

$$97. LSFQ = \sum_j LFQ_j$$

$$98. LSHQ = \sum_j LHQ_j$$

$$99. LSFMQ = \sum_j LFMQ_j$$

$$100. LSHMQ = \sum_j LHMQ_j$$

$$101. \sum_j KD_{k,j} = KS_j$$

$$102. IT = \sum_h SH_h + \sum_f SF_f + SG + SROW$$

$$103. IT_{PRI} = IT - IT_{PUBTOT} - \sum_i PC_i VSTK_i$$

$$104. \sum_j DS_{j,i} = DD_i$$

$$105. \sum_j EX_{j,i} = EXD_i$$

Gross domestic product

$$106. GDP^{BP} = \sum_j PVA_j VA_j + TIPT$$

$$107. GDP^{MP} = GDP^{BP} + TPRCTS$$

$$108. GDP^{IB} = \sum_j [Wfq LSFQ_h + Whq LSHQ_h + Wfnq LSFNQ_h + Whnq LSHNQ_h] + \sum_{k,j} R_{k,j} KD_{k,j} + TPROD_N + TPRCTS$$

$$109. GDP^{FD} = \sum_i PC_i [C_i + CG_i + INV_i] + \sum_i PE_i^{FOB} EXD_i - e \sum_i PWM_i M_i$$

Real variables

$$110. CTH_{h,REAL} = \frac{CTH_h}{PIXCON}$$

$$111. G^{REAL} = \frac{PIXGVT}{G}$$

$$112. GDP^{BP_REAL} = \frac{GDP^{BP}}{PIXGDP}$$

$$113. GDP^{MP_REAL} = \frac{GDP^{MP}}{GDB^{MP}}$$

$$114. GFCF_PRI^{REAL} = \frac{IT_{PRI}}{PIXINV_PRI}$$

$$115. GFCF_PUB^{REAL} = \frac{IT_{PUB}}{PIXINV_PUB}$$

Dynamic equations

$$116. IT_{PUB} = PK_{PUB} * \sum_{k,pub} IND_{k,pub}$$

$$117. IND_DAM_{k,dam} = \frac{Y_{k,dam} * IT_DAM}{PK_PRI}$$

$$118. IT_{PUB,TOT} = IT_{PUB} + IT_DAM$$

$$119. IT_{PRI} = PK_{PRI} * \sum_{k,bus} IND_{k,bus}$$

$$120. PK_{PRI} = \frac{1}{A_{k,PRI} \prod_i \left(\frac{PC_i}{PC_i^0} \right)^{Y_i^{INV_PRI}}}$$

$$121. PK_{PUB} = \frac{1}{A_{k,PUB} \prod_i \left(\frac{PC_i}{PC_i^0} \right)^{Y_i^{INV_PUB}}}$$

$$122. IND_{k,bus} = \gamma_{k,bus} \left[\frac{R_{k,bus}}{U_{k,bus}} \right]^{\sigma_{k,bus}^{inv}} \sigma_{k,bus}^{KD} KD_{k,bus}$$

$$123. U_{k,bus} = PK_{PRI} * (\delta_{k,bus} + IR_t)$$

$$124. U_{k,pub} = PK_{PUB} * (\delta_{k,pub} + IR_t)$$

L'impact du changement climatique sur la pauvreté des femmes. Application à la Bolivie

Résumé

En Bolivie, la vulnérabilité des femmes et des hommes à l'impact du changement climatique n'est pas la même en raison des différences régionales et de genre. Tout au long de ces thèses, nous utilisons des modèles d'équilibre général calculable liés à des micro-simulations pour évaluer les impacts liés au changement climatique et aux catastrophes climatiques. Dans le premier article, les scénarios analysent la baisse des rendements de la production agricole, la hausse des prix internationaux et les dommages causés au capital agricole par le changement climatique. Ces simulations révèlent des impacts négatifs sur la pauvreté et le bien-être, les femmes rurales étant les plus touchées. Dans le deuxième article, nous nous concentrons sur les catastrophes climatiques et présentons une analyse ex-post des dommages induits par des événements catastrophiques produits entre 2013-2014. La simulation révèle des impacts négatifs sur l'économie bolivienne, en particulier sur l'agriculture des régions des highlands. La disponibilité alimentaire est réduite, les prix des aliments augmentent et cela se traduit par une augmentation de l'insécurité alimentaire et de la pauvreté alimentaire, les ménages dirigés par des femmes étant les plus touchés. Le troisième article est une extension de l'article précédent. Un modèle dynamique y est utilisé pour analyser l'impact ex-post des catastrophes climatiques, ainsi que l'analyse des politiques de reconstruction. Les résultats révèlent que les dommages causés par les catastrophes ont des effets négatifs sur l'économie, tandis que les investissements dans la reconstruction ont des effets positifs. Cependant, il n'y a pas d'améliorations claires dans la réduction des inégalités de genre qui subsistent même après la reconstruction. Ces résultats révèlent la nécessité d'intégrer une perspective de genre dans l'analyse des catastrophes climatiques et dans les politiques de prévention qui vont au-delà de la reconstruction.

Mots clés : Changement climatique ; Catastrophes climatiques, Genre ; Travail domestique ; Pauvreté ; Sécurité alimentaire ; Modèle d'équilibre général ; Politique de reconstruction ; Bolivie

Abstract

Across Bolivia, the vulnerability of women and men to the impact of climate change is not equal due to regional and gender differences. Throughout these theses we use computable general equilibrium models linked to micro-simulations to assess impacts related to climate change and climate disasters. In the first article the scenarios consider the analysis of declining agricultural production yields, rising international prices, and damage to agricultural capital due to climate change. These simulations reveal negative impacts on poverty and welfare, with rural women being the most affected. In the second article we focus on climate disasters and present an ex-post analysis of the damage induced by catastrophic events produced between 2013-2014. The simulation reveals negative impacts on the Bolivian economy, particularly on agriculture of highlands. Food availability is reduced, food prices increase and this translates into increased food insecurity and food poverty, with female-headed households suffering the most. The third article is an extension of the previous article. In this chapter, a dynamic model is used to analyse the ex-post impact of climatic catastrophes, as well as the analysis of reconstruction policies. The results reveal that disaster damage has negative effects on the economy, while investment in reconstruction has positive effects. However, there are no clear improvements in reducing gender gaps that remain even after reconstruction. These results reveal the need to incorporate a gender perspective in the analysis of climate disasters and in prevention policies that go beyond reconstruction.

Keywords: Climate change; Climate disasters, Gender; Domestic work; Poverty; Food security; General Equilibrium model; Reconstruction policy; Bolivia.